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Liquid crystal composition for bistable liquid crystal devices

The invention is directed to liquid crystal (LC) compositions for use in
bistable liquid crystal devices and to bistable liquid crystal devices
5   containing said liquid crystal compositions.

Figure 1 is an illustration of zenithal bistability using grating alignment (with
the lines indicating the local director) showing a) the high tilt (continuous)
and b) the low tilt (defect) states.
10

Figure 2 depicts a) the VAN-HAN and b) the HAN-TN geometries for ZBD
showing the director distribution of the high and low tilt states.

Figure 3 shows a) the VAN-HAN and b) the HAN-TN geometries for ZBD
15   reflective devices.

Figure 4 shows the τ-V curve for the LC mixture MLC-6204-000 at 25°C
(pulse duration or time slot vs. voltage). The switching voltage ($V_{1000\mu s}$) and
operating window ($\Delta V_{1000\mu s}$) used for comparisons are indicated.
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Figure 5 illustrates the dual mode LCD operation principle: A laptop display
is displaying a proportion of static text and a proportion with a moving
image. The static text operates in the bistable mode, the moving image
operates in a monostable TFT-LCD mode.
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Electrooptical devices utilizing liquid crystal media for displaying
information are well known and used in a wide variety of technical
applications (see, for a review, H. Kawamoto, Proc. IEEE, 90, 460 (2002)).
Among these, nematic liquid crystal devices are the most prominent; there
30   are, for instance, twisted nematic (TN) liquid crystal devices (M. Schadt
and W. Helfrich, Appl. Phys. Lett., 18, 127 (1971)) and super-twisted
nematic (STN) liquid crystal devices (see, inter alia, T.J. Scheffer and J.
Nehring, Appl. Phys. Lett., 48, 1021 (1984)). These devices are
monostable, i.e. the liquid crystal medium is switched to an ON state by
35   application of a suitable voltage, and is allowed to switch to an OFF state
when the voltage applied falls below a lower voltage level.

In order to display complex information, electrooptical devices need to comprise a number of picture elements that can be switched independently of each other. However, when direct or even multiplex

5   addressing of pixels are used, the number of elements addressable in nematic liquid crystal displays is limited, in the first case by mere geometrical requirements of the electrical connections and in the second case by the steepness of the device's transmission versus the voltage curve.

10

This limitation can be overcome by incorporating thin film transistors (TFT) into each picture element. Such devices, also known as active matrix (AM) displays, enable addressing of a high number of picture elements and thus of large area, high resolution displays and with relatively low voltage

15   requirements. Some of these devices are also mechanically rather stable and have a wide temperature range.

Usually AM-TFT displays are operated in a monostable driving mode. Hence, the device has no intrinsic or internal memory and constant update

20   of the display even for static images is required. This may cause relatively high power consumption and rather poor battery lifetime.

Another type of liquid crystal device are displays with an internal memory effect, e.g. a bistable liquid crystal device. Bistability means that the

25   molecules of the liquid crystal medium inside the device can adopt two different stable states. Consequently, by applying a suitable addressing scheme, the liquid crystal molecules of the medium are switched into a first stable state that persists even after addressing; utilization of another addressing scheme causes the liquid crystal molecules to adopt a second

30   stable state that likewise persists after addressing. For some specific applications direct or multiplex addressing of such bistable liquid crystal compositions is suitable, and thus the more complicated AM addressing is not required for these applications. However, if desired, AM addressing may also be used for driving bistable liquid crystal devices.

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Ferroelectric liquid crystal displays using smectic liquid crystal materials can be made into bistable devices. They have, however, several disadvantages, e.g. lack of shock resistance, narrow operating temperature range, and low cell gap causing manufacturing difficulties.

5   Therefore, these ferroelectric liquid crystal devices are unlikely to fulfill the requirements to displays for the devices mentioned above.

However, not only ferroelectric smectic liquid crystals are capable of being used in bistable devices but also nematic liquid crystals. Besides other

10   approaches that utilize bistable bulk configurations adopted by nematic liquid crystals (see, for instance, I. Dozov et al., "Recent improvements of bistable nematic displays switched by anchoring breaking (BiNem®)", Proceedings SID 01 (2001), 16.1, 224 and references therewithin), a promising way of achieving bistability in a nematic liquid crystal display is

15   to use a surface alignment which can support two or more stable states. As discussed in literature (see, for instance, J.C. Jones, G. Bryan-Brown, E. Wood, A. Graham, P. Brett and J. Hughes, "Novel bistable liquid crystal displays based on grating alignment", in "Liquid Crystal Materials, Devices, and Flat Panel Displays", R. Shashidhar, B. Gnade, Eds., Proceedings of

20   SPIE Vol. 3955 (2000), 84 and references cited therein) two types, azimuthal and zenithal bistability, can be distinguished.

In the first instance (i.e. azimuthal bistability), the director of the liquid crystal molecules in the display having a grating alignment on the surface

25   of one of the display cell's plates (or substrates) will lie parallel to said plate in both stable states; that means that switching between the stable states occurs within the plane of the display cell's plates (see, for instance, WO 92/00546 and WO 95/22077 which describes the use of a substrate having a bigrating alignment layer). However, reproducing selection of the

30   stable states is found to be difficult and switching generally requires a high switching voltage.

On the other hand, zenithal bistability is observed when the zenithal bistable surface is used (see Figure 1; the tiny lines represent the local

35   director of the liquid crystal molecules that are oriented by interaction with the surface grating and appropriate alignment layer). With such a surface,

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the director of the liquid crystal molecules has two possible configurations with different pretilt angles in the same azimuthal plane (i.e. the plane perpendicular to the surface of the display cell's substrate). The first state is the continuous high tilt state (C) while the second state is the defect low
5   tilt state (D). The grating of the zenithal bistable surface is defined by its amplitude a and its pitch L; typical values are for L of about 1 µm and for a of about 0.6 to 0.8 µm (see WO 97/14990 and, for more details, WO 02/08825; and J.C. Jones, G. Bryan-Brown, E. Wood, A. Graham, P. Brett and J. Hughes, "Novel bistable liquid crystal displays based on grating
10 alignment", in "Liquid Crystal Materials, Devices, and Flat Panel Displays", R. Shashidhar, B. Gnade, eds., Proceedings of SPIE Vol. 3955 (2000), 84).

A homeotropic orientation can be induced, for example by coating the
15 grating with a homeotropic alignment layer. This homeotropic alignment induced orientation ensures that the director of the liquid crystal molecules does not lie parallel to the grooves of the grating. Although the orientation of the director of the liquid crystal molecules is perpendicular to the (local) surface, i.e. varying with the location on the surface along a direction
20 perpendicular to the grooves, the orientation in the "bulk" is very much influenced by the opposite surface alignment in both states. Switching from one stable state to the other may be achieved by applying a simple electrical pulse thereby causing a switch from a black display or picture element to a white one (or vice versa) with the appropriate polariser
25 configuration and retardation. Switching back to the original state occurs upon application of a pulse of opposite polarity thereby causing a switch from white to black (or vice versa). Switching may also be induced by using pulses of same polarity but with much higher voltages (also referred to as "reverse switching"); however, reverse switching is a detrimental effect
30 which limits the operation of a zenithal bistable nematic device in terms of the addressing and so a high a voltage as possible is desired for the reverse switching.

In general, for obtaining zenithal bistability only one of the two display cell
35 substrates is provided with a surface grating. The opposite plate may have a surface providing a homeotropic alignment of the liquid crystal director

(vertically aligned nematic or VAN mode, see Figure 2a)) or a surface
inducing planar alignment of the director (TN mode, see Figure 2b))
thereby causing the twisting of the liquid crystal director around the axis
perpendicular to the substrates across the cell for the low tilt state. Exact

5   details regarding cell geometry and configuration, exact cell parameters,
addressing means, assembling of the entire zenithal bistable device
(including use of polarisers) etc. are disclosed in WO 97/14990; E.L.
Wood, G.P. Bryan-Brown, P. Brett, A. Graham, J.C. Jones, and J.R.
Hughes, "Zenithal Bistable Device (ZBD^{TM}) Suitable for Portable

10   Applications, SID 00 Digest (2000), 124; J.C. Jones, J.R. Hughes, A.
Graham, P. Brett, G.P. Bryan-Brown, and E.L. Wood, "Zenithal Bistable
Devices: Towards the electronic book with a simple LCD", IDW '00 (2000),
301; J. C. Jones, S. M. Beldon and E. L. Wood, "Greyscale in Zenithal
Bistable LCD: The Route to Ultra-low Power Colour Displays", seminar talk

15   on the ASID meeting 2002 of the Society for Information Display,
Singapore, September 2002; and the detailed discussion given in J.C.
Jones, G. Bryan-Brown, E. Wood, A. Graham, P. Brett and J. Hughes,
"Novel bistable liquid crystal displays based on grating alignment", in
"Liquid Crystal Materials, Devices, and Flat Panel Displays", R.

20   Shashidhar, B. Gnade, eds., Proceedings of SPIE Vol. 3955 (2000), 84,
and references cited therein.

Utilizing zenithal bistability in electrooptical devices offers attractive
features, inter alia:

25   ▪ Image retention on a display without continuous update combined
with
           ▪ High mechanical shock stability
           ▪ Low power consumption since the display only needs addressing
when the image changes

30   ▪ Eminent suitability for use with plastic substrates

Moreover, both transmissive and reflective modes are possible in displays
utilizing zenithal bistability. A display using a transmissive mode requires a
backlight on the display's rear side being permanently switched on. This

35   contributes significantly to the overall power consumption of the display.
Further, when using the transmissive display under conditions of high

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brightness, e.g. in direct sunlight, the contrast may become rather poor rendering the display almost unreadable. To the contrary, a reflective display has no backlight but a reflector on its rear side thereby utilizing the surrounding light falling on the display for its illumination by reflection.

5 Power consumption is lower compared to the transmissive display, and the contrast is good under conditions of high brightness making the reflective display especially useful for outdoor and daylight use. However, under poor illumination conditions, e.g. in the darkness, the reflective display becomes hardly readable. Therefore, so-called transflective displays have

10 been suggested and disclosed (see, for instance, US 2003/0043323 A1) in order to overcome the disadvantages of both transmissive and reflective modes while still utilizing their advantages. In general, a transflective display is utilizing the reflective mode using a partial reflector on the rear side of the display so that in the transmissive mode a backlight can be

15 turned on in order to fit the lightning conditions.

Reflective and transflective modes both may be applied to displays utilizing zenithal bistability (see, e.g., J.C Jones, P. Worthing, G. Bryan-Brown, E. Wood, SID 03 Digest (2003), P-14.1). The display geometries that are

20 favoured for these applications are the vertically aligned nematic (VAN) mode for a single polarizer device in the retardation mode (see Figure 3a)) and the twisted nematic (TN) mode for single and two-polariser devices in the polarization mode (with the two-polariser device shown in Figure 3b)). (However, other display geometries like, for instance, the Mixed mode of

25 twisted nematic liquid crystal compositions (MTN mode; S.-T. Wu, C.-S. Wu, Appl. Phys. Lett. 68 (11) 1996, 1455) may also be used.) The two-polariser reflective device works in the modified TN 1st minimum condition (*C.H. Gooch and H.A. Tarry*, "The Optical Properties of Twisted Nematic Liquid Crystal Structures with Twist Angles ≤90°", J. Appl. Phys. D: Appl.

30 Phys., Vol. 8, p.1575-1584, 1975) with $d_{opt} \approx \frac{\sqrt{3}}{2}\frac{\lambda_0}{\Delta n} + 0.4$, whereby λ_0 is

0.555 μm and d_{opt} is the optimal cell gap as for the standard transmission mode. For optimum viewing angles it preferably uses the lowest defect state pretilt on the grating of the zenithal bistable surface, which in turn

35 actually requires a lower Δn for the same cell gap. The 0.4μm factor is an adjustment to give the best optical performance for a given birefringence

with the defect state pretilt currently used. For the single polariser TN
mode, however, the twisted state is used to give the black state and the
hybrid state is then the white state, as it has no retardation if the
appropriate polariser orientation is used.

5

For the single polariser VAN-HAN mode (Fig. 3a)) the VAN state (high tilt
C state in Fig. 3a)) does cause any retardation and so appears white
against a reflector. The hybrid aligned nematic (HAN) state (low tilt D state
in Fig 3a)), however, will have some retardation and if this acts as a

10   quarter-wave plate (i.e. with the two passes then equivalent to a half-wave
plate causing a 90° rotation of the plane of polarized light) it appears black
as there is no transmission of the reflected light at the polariser. (Here, the

optimal cell gap is given by $d_{opt} \approx \frac{\lambda_0}{2\Delta n} + 0.4$.) The optical performance of

15   such a device may be improved by using a quarter-wave plate between the
polariser and liquid crystal cell, and in this case the optical states are
reversed (i.e. the VAN state is black and the HAN state is white).

Besides the assembly and make up of the zenithal bistable display,
20   another key issue to the zenithal bistable device technology is the nematic
liquid crystal medium used inside the display cell.

The zenithal bistable device and hence the liquid crystal medium have to
meet several requirements more or less depending on the specific use of
25   the device. Since there is no consistent theory so far that might predict the
physical variables to be optimized, it turned out to be helpful to use a set of
(semi-)empirical parameters for evaluating liquid crystal media with respect
to their usefulness in zenithal bistable nematic devices. These are
illustrated in the so-called τ-V curve for switching voltages of pulse duration
30   τ and for 10 and 90% switching levels with opposite polarities (see figure
4) for a liquid crystal mixture of the prior art, namely MLC-6204-000 of
Merck KGaA, Darmstadt, Germany.

Firstly, in order to minimize power consumption, to allow more flexibility
35   with the addressing of the device's picture elements and to remain within
the limits of standard commercial electronic drivers and associated

components, a low *switching field* and correspondingly a low *operating voltage* is desirable for switching from one bistable state to the other. The following applies to either the VAN (without a quarter-wave plate) or TN modes when viewed in transmission between crossed polarisers. For

5   material comparison one can determine the switching field E for a pulse (usually a 100 µs or 1000 µs pulse duration) from the switching voltage V that gives a transmission change from, e.g., 0 to 90% transmission (black-to-white; B-W or C-D) for a particular liquid crystal mixture in a given test cell providing zenithal bistability. (In general, one can also use the 100 to

10   10% transmission change transition of white-to-black, W-B or D-C, where the switching field of which may be higher or lower than the B-W transition depending on the grating's shape and dimensions.) For practical reasons, the average of both the black-to-white transition and the white-to-black transition may be used as in the present specification. In order to take into

15   account the electric field effect of the grating (dependent on the relative permittivities of the liquid crystal and the grating, the grating shape and the cell gap) the value of E actually measured is corrected to distinguish the field just across the liquid crystal again for comparison purposes giving the *corrected switching field* $E_{LC@1000µs}$ for a 1000 µs pulse. Here, an additional

20   estimated factor of 1.5µm is added to the cell gap d when calculating the field just across the liquid crystal:

$$E_{1000\mu s} = V_{1000\mu s}/d \text{ and } E_{LC@1000\mu s} = V_{1000\mu s}/(d+1.5) \text{ where d is in } \mu m.$$

25   Multiplying $E_{LC@1000µs}$ with *optimum cell gap* d_{opt} gives the *operating voltage* V_{opt} corresponding to the optimum cell gap for a 1000 µs pulse for just the liquid crystal. $E_{LC@1000µs}$ and so V_{opt} depend on the liquid crystal medium used. Here, the optimum cell gap is considered for the VAN-HAN mode of Fig. 3a) but comparisons can also be made for the single

30   polariser HAN-TN mode. If the hybrid state is to act as a quarter-wave plate, the optimum cell gap can be approximated by $d_{opt} = (\lambda/2\Delta n) + 0.4$ (in µm) with $\lambda = 0.555$ µm and Δn being the optical anisotropy of the liquid crystal medium, and the additional factor of 0.4µm is included as this has been found to give the best optical performance for the gratings currently

35   used. The modified 1st minimum condition for the two polariser HAN-TN mode is then $d_{opt} = (\lambda\sqrt{3}/2\Delta n) + 0.4$. As mentioned earlier, the defect state

pretilt can be increased to permit larger cell gaps without material improvements but the viewing angle is poorer (and the necessary cell gap may still be much less than 5μm in some cases). It is desirable to have the defect state pretilt less than 20°.

5

The second empirical parameter that might be taken into account is the *operating window* ΔV_{opt} corresponding to the optimum cell gap. It describes the effect of reverse switching: When applying a pulse with a given time slot of, e.g. 400 μs or 1000 μs, and a defined pulse polarity, e.g.

10   B-W, one observes the desired switching at a specific value of the switching field and a further reverse switching (e.g. W-B in this case) which is not induced by a pulse of inverse polarity but by a pulse of the same polarity at an increased switching field. For technical purposes, obviously said operating window ought to be as wide as possible to permit more

15   flexibility of the driving schemes used and particularly in relation to achieving good greyscale operation (see J. C. Jones, S. M. Beldon and E. L. Wood, "Greyscale in Zenithal Bistable LCD: The Route to Ultra-low Power Colour Displays", seminar talk on the ASID meeting 2002 of the Society for Information Display, Singapore, September 2002. In the

20   example disclosed in this paper for a sub-divided grating, the regions have pitches of 0.6μm, 0.7μm, 0.8μm and 0.9μm and the switching threshold variation across the bistable window was 6V. Therefore, to achieve the maximum number of such error-free greyscale levels the operating window has to be greater than 6V, meaning $\Delta E_{LC@1000μs}$ should be greater than

25   ~1.5V/μm but preferably greater than 5V/μm). The corresponding field can be represented by $\Delta E_{LC@1000μs}$, that is the corrected difference between the 90% reverse switching field and the 90% B-W switching field for a 1000 μs pulse:

30      $$\Delta E_{1000μs} = \Delta V_{1000μs}/d \text{ and } \Delta E_{LC@1000μs} = \Delta V_{1000μs}/(d+1.5) \text{ where d is in } μm.$$

Taking into account the optimum cell gap d_{opt} by multiplying with $\Delta E_{LC@1000μs}$ eventually gives the operating window ΔV_{opt} ($d_{opt}\Delta E_{LC@1000μs} = \Delta V_{opt}$).

35

A further parameter of great importance is the *clearing point* T_{NI} of the liquid crystal medium describing the temperature at which the nematic mixture becomes isotropic. For many technical purposes and for increasing the variability of electrooptical devices utilizing zenithal
5   bistability (and so the possible applications), liquid crystal media having a high clearing point, preferably of at least 70 °C, more preferred at least 80 °C or more, are desired.

Still another parameter, the *optical response time* τ_{opt} corresponding to the
10   optimum cell gap, describes how fast the liquid crystal medium changes between stable states upon application of an electric pulse. It can be determined by measuring the response time τ for the 10-90 % B-W transition, for example using a 100 µs or a 1000 µs pulse, in the actual test cell; then, in order to normalize the experimental values, τ is multiplied by
15   $(d_{opt}/d)^2$ giving τ_{opt} (with d_{opt} being the optimum cell gap as calculated above for V_{opt} and d being the actual cell gap of the test cell used). The W-B transition is much faster (less than 1ms) and so indeed the B-W response time is of most importance when assessing the properties of the liquid crystal medium used. The smaller τ_{opt} the faster the optical response
20   of the liquid crystal medium. A small τ_{opt} (of about 60 ms or, preferably, less than about 35 ms) may be desirable for certain electrooptical applications.

A further parameter being of some relevance for reflective and transflective
25   bistable nematic devices is the *birefringence* Δn of the liquid crystal mixture used. Due to the correlation between Δn and the cell gap d, Δn needs to meet specific requirements if displays having a practically useful cell gap of about 5 µm are employed. (A much smaller cell gap, for example of less than 3 µm, is not desired due to practical manufacturing reasons.) With
30   regard to the two-polariser reflective mode (see, e.g., Figure 3b)) and to the TN 1st minimum condition as given previously, Δn is desirably of about 0.11 or less, particularly when a lower defect state pretilt at the grating is favoured for improved optical performance.

35   Those liquid crystal media the use of which in zenithal bistable devices have been described in the prior art do not meet all the parameter

requirements outlined above. Even liquid crystal mixture MLC-6204-000 (available from Merck KGaA, Darmstadt, Germany) that has been used in zenithal bistable devices as the preferred medium (WO 01/40853, Example 6; J.C. Jones, G. Bryan-Brown, E. Wood, A. Graham, P. Brett

5   and J. Hughes, "Novel bistable liquid crystal displays based on grating alignment", in "Liquid Crystal Materials, Devices, and Flat Panel Displays", R. Shashidhar, B. Gnade, Eds., Proceedings of SPIE Vol. 3955 (2000), 84) has a clearing point T_{NI} of only 62.4 °C that is rather low for use in zenithal nematic bistable device for many possible applications, especially portable

10   ones. Furthermore, it has a rather high V_{opt} and a rather small ΔV_{opt}.

The present invention therefore encounters the problem to provide a liquid crystal composition that is suitable for use in a bistable liquid crystal device and especially in a reflective or transflective zenithal bistable nematic

15   device and has an improved set of properties.

The problem is solved by a liquid crystal composition for use in a bistable liquid crystal device, said device being preferably a zenithal nematic liquid crystal device, whereby said composition comprises a component (π) said

20   component (π) containing one or more compounds having a phenyl ring of formula A

25   A
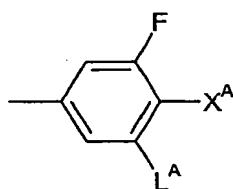
whereby

30   X^A is F, Cl, SF_5, NCS, or a C_1 to C_8 alkanyl, alkenyl or alkoxy radical
        substituted with at least one F atom; and
        L^A is H or F.

35   A further subject matter of this invention is a bistable liquid crystal device comprising
        • two outer substrates which, together with a frame, form a cell;

- a liquid crystal composition present in said cell;
- electrode structures with alignment layers on the inside of said outer substrates whereby at least one alignment layer comprises an alignment grating that permits the liquid crystal composition to adopt at least two different stable states whereby the assembly of said electrode structures with said alignment layers being such that in a first driving mode a switching between the said at least two different stable states is achieved by applying suitable electric signals to said electrode structures;
- whereby said liquid crystal composition is said liquid crystal composition as described above and below and that comprises said component (π).

In particular, said bistable liquid crystal device is a zenithal bistable nematic liquid crystal device in which said electrode structures with alignment layers on the inside of said outer substrates have at least one alignment layer that comprises an alignment grating that permits the compounds of said liquid crystal composition to adopt at least two different stable states with different pretilt angles in the same azimuthal plane whereby the assembly of said electrode structures with said alignment layers being such that a switching between the said at least two different stable states is achieved by applying suitable electric signals to said electrode structures.

The bistable liquid crystal device according to the invention may be, for instance, a transmissive, reflective or transflective display; it may even be of a more complex device construction as it is known in the art. It is particularly preferred that the bistable liquid crystal device according to the invention is a reflective or transflective display and especially a reflective or transflective zenithal bistable nematic liquid crystal display.

Furthermore, it has surprisingly been found that the liquid crystal composition for bistable liquid crystal devices according to the present invention are not only suitable for conventional passive matrix (PM) (or direct or multiplex addressed) bistable liquid crystal devices but for bistable liquid crystal devices that may be operated over an active matrix (AM),

particularly over an AM addressing with a TFT (thin film transistor) array. (TFT-AM displays are well known to those skilled in the art and generally described in, e.g., the Merck brochure "Flüssigkristalle für Aktivmatrix-Flachbildschirme" [Liquid Crystals for Active Matrix Flat Panel Displays], M.

5   Heckmeier, G. Lüssem, K. Tarumi, W. Becker, Merck KGaA, Darmstadt, Germany, 2003.) Moreover, this further allows the use of the liquid crystal composition according to the present invention in a liquid crystal device that is operated and/or operable in a so-called "dual mode" one of which being a bistable mode and the other one being a monostable mode.

10   Therefore, a further subject matter of the present invention is a bistable liquid crystal device that comprises electrode structures the assembly of which allowing the switching between said at least two different stable states in said first driving mode (i.e. the bistable mode) and a switching of said liquid crystal composition in a second driving mode that is the

15   monostable mode. This device operated and/or operable in the dual mode will be described in greater detail somewhere below in this specification. (It should be recognized that said bistable mode may be addressed by a passive matrix (PM) or direct or multiplex addressing or even an active matrix (AM). In the context of the present invention it is preferred that both

20   said bistable mode and said monostable mode of said dual mode are driven by an active matrix (AM) TFT mode.)

It will be acknowledged that the invention is described hereinafter primarily with regard to the use of the liquid crystal composition above in a zenithal

25   bistable nematic liquid crystal device although it may be used in other liquid crystal devices as well, for instance, in bistable liquid crystal devices like azimuthal bistable liquid crystal devices as disclosed, inter alia, in WO 92/00546 and WO 95/22077. Thus, details are given for the zenithal bistable nematic liquid crystal device but can easily be adapted to the

30   requirements of other types of bistable liquid crystal devices.

The cell that is part of the zenithal bistable nematic device according to the invention may be any conventional cell that allows the nematic liquid crystal composition to adopt at least two different zenithal bistable states.

35   Two possible stable states are schematically depicted in Figure 1. The two different zenithal bistable states are characterized by two different pretilt

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angles that are adopted by the liquid crystal molecules in the same
azimuthal plane. The cell comprises a frame and two outer substrates or
plates and has electrode structures with alignment layers on the inside of
said substrates. At least one of these alignment layers has an zenithal
5   alignment grating known to those skilled in the art and as described, for
instance, in WO 97/14990, WO 01/40853, WO 02/08825, and J.C. Jones,
et al., Proceedings of SPIE Vol. 3955 (2000), 84.

The electrode structures are assembled with the alignment layer(s) in such
10   a way that (in the case of two stable states) switching from one stable state
to the other can be achieved by applying suitable electric signals to the
electrode structures thereby applying said electric signals to the liquid
crystal composition inside the cell. Commonly, single pulses can be used
as such suitable electric signals. Details are known to the artisan and
15   described in WO 97/14990, WO 01/40853, WO 02/08825, J.C. Jones, J.R.
Hughes, A. Graham, P. Brett, G.P. Bryan-Brown, IDW '00 (2000), 301, J.C.
Jones, et al., Proceedings of SPIE Vol. 3955 (2000), 84, and E. L. Wood,
P. J. Brett, G. P. Bryan-Brown, A. Graham, R. M. Amos, S. Beldon, E.
Cubero and J. C. Jones, "Large Area, High Resolution Portable ZBD
20   Display", SID 02 Digest (2002), 22-25.

The substrate opposite to the substrate having the grating alignment layer
may have a homeotropic alignment due to suitable surface treatment (see
Figure 2a)). Switching upon application of an electric pulse occurs from the
25   high tilt or vertically aligned state to the low tilt or hybrid aligned state. This
switch gives a black-to-white (B-W) change if the cell is placed between
crossed polarisers (at 45° to the grating direction), with the brightest white
state obtained when the vertically aligned state acts as a half-wave plate
($d\Delta n=\lambda/2$). This switching mode is called *VAN mode*. Zenithal bistable
30   devices utilizing the VAN mode are very insensitive to cell gap variations.
They require additional optical compensators to achieve wide viewing
angles. A second switching mode of zenithal bistable devices is called *TN
mode* (see Figure 2b)): The substrate opposite to the substrate having the
grating alignment layer has a alignment layer, usually of rubbed polyimide,
35   causing planar alignment of the liquid crystal molecules on said substrate.
This in turn causes the twisting of the liquid crystal director around their

axis perpendicular to the substrates across the cell. Switching upon
application of an electric pulse now occurs from the low tilt or twisted
aligned state to the high tilt or hybrid-aligned state. This switch gives a
black-to-white (B-W) change if the cell is placed between parallel

5   polarisers and using the TN 1st minimum condition accounting for the
influence of the ordinary refractive index of the hybrid state. Due to a high
normal incidence contrast ratio additional optical compensators for
achieving wide viewing angles are not required in a transmissive display.
Therefore the TN mode is preferred for some of the technical applications

10   of zenithal bistable nematic devices.

It is also possible to build up zenithal bistable reflective (or transflective)
displays that are preferred embodiments of the present invention. Figure
3a)) depicts a reflective zenithal bistable nematic device in the VAN-HAN

15   mode utilizing a single polariser (as explained above with regard to Figure
3a)). Figure 3b) depicts a reflective zenithal bistable device in the HAN-TN
mode utilizing two polarisers one on each substrate of the cell (as
explained above with regard to Figure 3b)).

20   For details of the build-up of zenithal bistable devices, also with regard to
the polarisers used, it is referred to WO 97/14990, E.L. Wood, G.P. Bryan-
Brown, P. Brett, A. Graham, J.C. Jones, and J.R. Hughes, SID 00 (2000),
124, and E. L. Wood, P. J. Brett, G. P. Bryan-Brown, A. Graham, R. M.
Amos, S. Beldon, E. Cubero and J. C. Jones, "Large Area, High

25   Resolution Portable ZBD Display" SID 02 Digest (2002), 22-25.

With regard to the addressing of the bistable liquid crystal device,
especially the zenithal bistable nematic liquid crystal device, in which the
liquid crystal composition described hereinbefore and hereinafter is used

30   according to the invention, the conventional passive matrix (PM)
addressing is usually sufficient for displaying information that is updated
only infrequently. However, there are several reasons why it might be
desirable to operate a bistable liquid crystal display over an active matrix.
When displaying true video (i.e. fast changing images) the size of the

35   display (i.e. the number of rows) for a PM device is limited by the time it
takes to address all of the lines sequentially, and this ought to be

< 16.7 ms or else the updating can be observed by the human eye. This
means that if, for instance, the line address time were 100 μs then the
maximum number of lines would be limited to 167 (16.7 ms / 100 μs).
However, one way to address a very large panel displaying video-rate
5   information would be to use AM addressing with a TFT array.

This becomes particularly important when the optical response of the liquid
crystal composition in the display driven in the bistable mode is above
about 16.7 ms. Then the bistable mode alone is not capable of displaying
10   video-rate information. As most PM bistable liquid crystal mixtures have
longer response times than this, a way around the problem is to operate
the device in what is known as the dual-mode format. This essentially
means that for static or infrequently updated images the display would be
operated in the bistable mode in the usual way but, for instance, if the
15   geometry used is the TN one (or the VAN one) then the display could also
be operated in the standard monostable TFT-TN mode (or the TFT-VAN
mode, respectively) for fast changing images. It should be recognized that
said bistable mode may be addressed by a passive matrix (PM) or direct or
multiplex addressing or an active matrix (AM). In the context of the present
20   invention it is preferred that both said bistable mode and said monostable
mode of said dual mode are driven by an active matrix (AM) TFT mode.

However, this implies that the liquid crystal composition used in the device
operated and/or operable in the dual-mode format must accomplish
25   specific requirements of both the "fast switching" monostable TFT mode
and the somewhat "slower switching" bistable liquid crystal mode at the
same time.

It has been found by the inventors that the liquid crystal composition for
30   use in bistable liquid crystal devices exhibit an improved set of parameters
making the composition suitable for the conventional bistable mode
(especially the zenithal bistable nematic mode) as well as the dual-mode
format. These parameters are, inter alia, operating voltage and, especially,
clearing point and voltage holding ration (VHR). The operating voltage is in
35   a range useful for operating a zenithal bistable nematic liquid crystal
device either in the conventional or a dual mode. It should be noticed that,

for instance, the clearing point of the liquid crystal compositions for use in the zenithal bistable nematic devices of the invention is significantly higher than the clearing point of liquid crystal mixtures previously used in zenithal bistable nematic devices. Moreover, the birefringence can be adjusted appropriately for transmissive, reflective and transflective displays. What is more, the operating window (ΔV_{opt}) is found to be much broader (it is generally > 3 V/μm) than in liquid crystal compositions for use in bistable liquid crystal devices previously known, and thus reverse switching does not impose any practically relevant problems here. Furthermore, in certain embodiments of the invention the optical response time τ_{opt} is decreased significantly. The liquid crystal compositions according to the present invention also show an extended nematic phase range.

At the same time the VHR of the liquid crystal composition of the invention is high enough for use of AM addressing with a TFT array. This is necessary because in a standard active matrix (AM) LCD, each pixel is addressed independently by a thin film transistor (TFT) (or sub-pixel when each pixel consists of more than one colour). The transistor charges a pixel and acts electrically as a capacitor while all the other rows of the matrix are addressed. During the remainder of the frame time (typically 16.7ms corresponding to a frequency of 60Hz) the voltage drop across an addressed pixel must be as small as possible to avoid any change in contrast. The VHR is used to gauge this and is defined as the ratio of the root mean square (RMS) voltage during a single frame to the initial voltage value (V_0), and is usually expressed as a percentage:

$$\text{VHR} = \frac{1}{V_0} \left| \frac{1}{T_f} \int_0^{T_f} \left(V_0 \exp^{-t/RC} \right)^2 dt \right|^{1/2}$$

where T_f is the frame time and RC is the time constant. VHR's > 90% and especially > 95% over the temperature operating range (and > 90% under severe UV loads) are usually required and achieved by the liquid crystal composition described and claimed herein. Some specific embodiments of the present invention even show VHR values of > 97% and especially of ≥ 98%. (The measurement of VHR's is usually performed according to proceedings known from the literature [S. Matsumoto et al., Liquid Crystals 5, 1320 (1989); K. Niwa et al., Proc. SID Conference, San Francisco, June 1984, p. 304 (1984); G. Weber et al., Liquid Crystals 5, 1381 (1989)]). For

- 18 -

the purpose of this specification, however, the term "VHR" refers
hereinafter to the voltage holding ratio over the temperature operating
range, unless specified otherwise.

5   Conventional bistable liquid crystal devices have been discussed in detail
        hereinbefore with specific regard to zenithal bistable nematic liquid crystal
        devices. Devices utilizing a dual-mode format have also been known and
        described in the literature, for instance in WO 02/29775 A1 and
        WO 02/29776 A1 (both utilizing bistable chiral nematic liquid crystal
10   material) as well as in WO 03/044763 A1. In general, such a dual-mode
        format can be described as follows:

        In information display applications, such as notebook computers utilising
        the Microsoft Windows™ operating system, or in the emerging field of
15   interactive media, it is possible that the liquid crystal display may be
        expected to simultaneously display both a static and a moving image, with
        the majority of the display displaying static text and a small window
        displaying video. The diagram in Figure 5 below is a graphical
        representation of this. Whereas it is possible to adopt such a visual
20   appearance to the display in a conventional AM liquid crystal display, it is
        necessary to constantly update the entire display, as there is no inherent
        bistability. In the dual-mode display, the portion of the display displaying
        static text could be driven using an addressing scheme that utilises the
        bistable mode, and the portion of the display displaying a video image
25   could be driven utilising an addressing scheme that utilises the
        conventional monostable mode. Thus, in principle each and every
        individual picture element (pixel) of the display can be driven in either
        mode. The combination of the inventive liquid crystal mixture concept, the
        bistability enabling surface, and appropriate drive schemes and electronics
30   enable this.

        In one embodiment of the present invention the liquid crystal composition
        for bistable liquid crystal devices, especially zenithal bistable nematic liquid
        crystal devices, is essentially free of compounds having a terminal ring to
35   which at least one CN substituent is attached directly or indirectly. This
        means that liquid crystal compositions according to the invention may

comprise besides said component (π) further compounds but should not comprise any substantial amounts (i.e. not more than about 1 to 2 weight% of the total weight of the mixture) of compounds with an end ring substituted with at least one cyano group (i.e. direct attachment) or a group

5   that itself is substituted with at least one cyano group (e.g. a CN substituted alkyl radical) (i.e. indirect attachment). Preferably, the liquid crystal composition of this embodiment is completely free of such cyano substituted compounds. In this embodiment, VHR is sufficiently high, usually above 95%, preferably above about 97% and especially preferably

10   above about 98%. The further compounds comprised in the bistable liquid crystal composition of this specific embodiment are, for instance, selected from those of formulas III to XIV as described in more detail elsewhere in this specification.

15   In still another preferred embodiment of the invention said component (π) is comprised in the liquid crystal composition according to the invention in an amount of at least 60 weight% or more (based on the total weight of the composition), especially in an amount of at least 80 weight%. (Since the liquid crystal composition of this embodiment may or may not comprise

20   further compounds not encompassed by component (π), it should be noted that compounds having a terminal ring bearing at least one direct or indirect -CN substituent may or may not be among these further compounds. However, it is preferred that the liquid crystal composition according to this embodiment of the present invention is essentially free of

25   cyano substituted compounds, i.e. the composition does not contain more than about 1 to 2 weight% (based on of the total mixture) of CN substituted compounds. It is even more preferred that the compositions of this embodiment are completely free of such cyano substituted compounds.)

30   The liquid crystal composition according to the present invention may consist essentially or completely of said component (π) (i.e. 100 weight% of the mixture). It is, however, especially preferred that further compounds besides component (π) are comprised by the liquid crystal composition of the invention and that component (π) is contained in an amount of up to 99

35   weight%, more preferred in an amount of up to 95 weight%.

$$R^{11} - A^{11} - Z^{11} - A^{12} - Z^{12} \underset{L^{11}}{\overset{F}{\diagdown}} X^{11}$$

I

$$R^{21} - A^{21} - Z^{21} - A^{22} - Z^{22} - A^{23} - Z^{23} \underset{L^{21}}{\overset{F}{\diagdown}} X^{21}$$

II
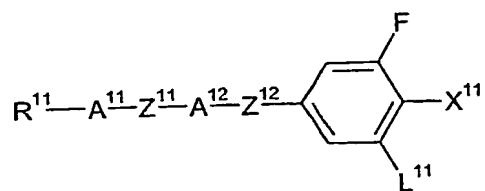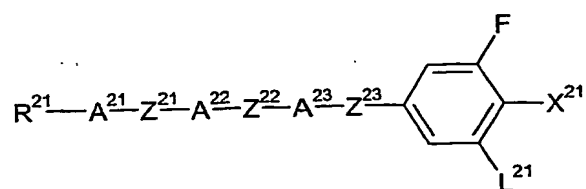
$$R^{21}\text{—}A^{21}\text{—}Z^{21}\text{—}A^{22}\text{—}Z^{22}\text{—}A^{23}\text{—}Z^{23}\text{—}\hspace{-2mm}\text{(benzene ring with F, X}^{21}\text{, L}^{21}\text{)}$$
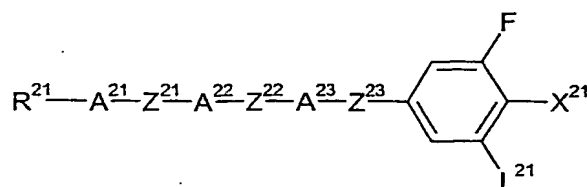
II

whereby

R^{11} and R^{21} are independently of each other C_1-C_{15} alkyl which is unsubstituted or mono- or poly-substituted with halogen and in which one or more of the CH_2 groups may be replaced independently of each other by -O-, -S-, -CH=CH-, -C≡C-, -CO-O-, -OC-O- such that there are no hetero atoms adjacent to each other;

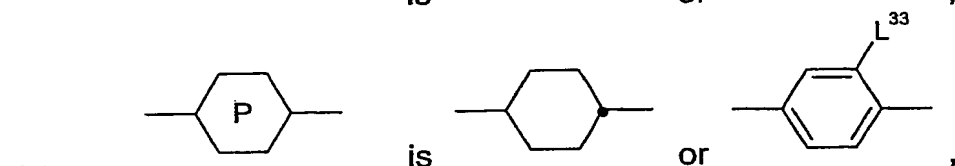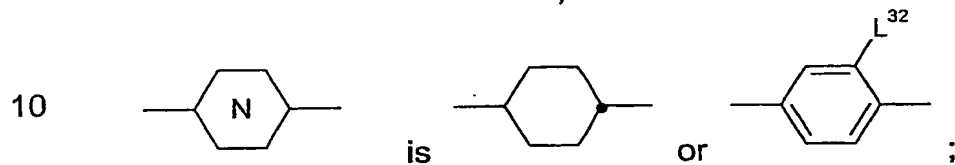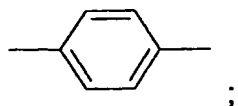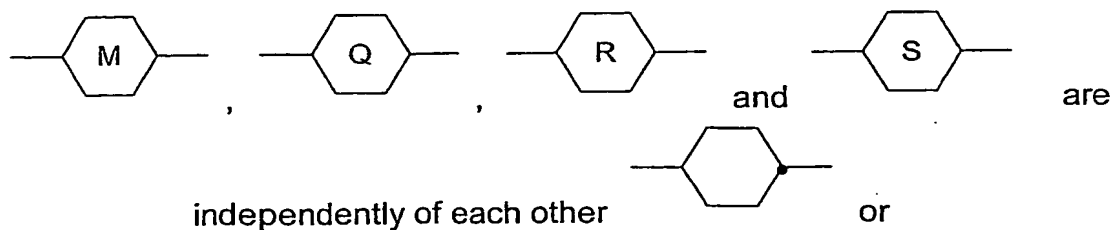Z^{11}, Z^{12}, Z^{21}, Z^{22}, Z^{23} are independently of each other a single bond, -CO-O-, -O-CO-, -CH$_2$O-, -OCH$_2$-, -CF$_2$O-, -OCF$_2$-, -CH$_2$CH$_2$-, (-CH$_2$CH$_2$-)$_2$, -CF=CF-, -CF$_2$CF$_2$-, -CH$_2$CF$_2$-, -CF$_2$CH$_2$-, -CH=CH- or -C≡C-;

X^{11} and X^{21} are independently of each other is F, Cl, SF$_5$, NCS, or a C_1 to C_8 alkanyl, alkenyl or alkoxy radical substituted with at least one F atom;

L^{11} and L^{21} are independently of each other H or F; and

A^{11}, A^{12}, A^{21}, A^{22} and A^{23} are independently of each other one of the following rings:
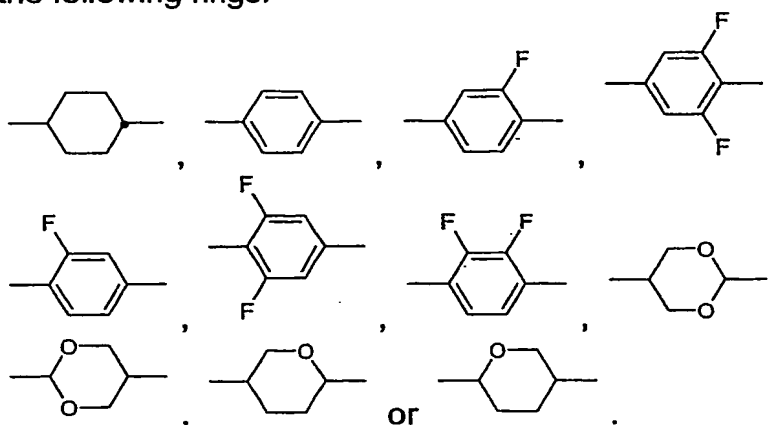
With regard to compounds of formula I it is more preferred that

R^{11} is a C_1 to C_8 alkanyl, alkenyl or alkoxy radical unsubstituted or substituted with at least one F atom, especially an

unsubstituted and straight-chain alkanyl or alkenyl radical with 2, 3, 4, 5, 6 or 7 carbon atoms;

L^{11} is H or F, especially F;

X^{11} is F or Cl, especially F;

Z^{11} and Z^{12} are a single bond, $-CF_2O-$ or $-CO-O-$ whereby at least one of Z^{11} and Z^{12} is a single bond;

A^{11} is

or

; and

A^{12} is

or
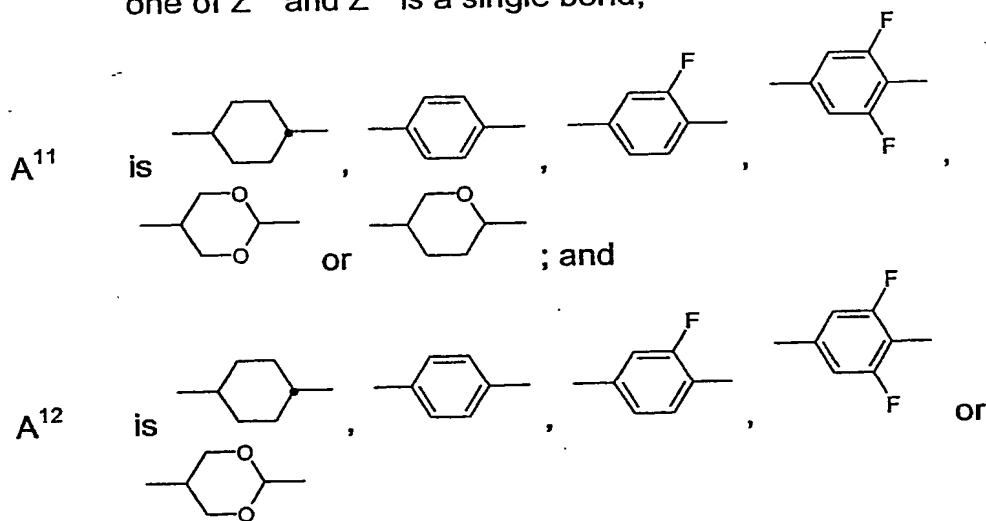
Preferred subformulas of formula I are inter alia:

I-1

I-2
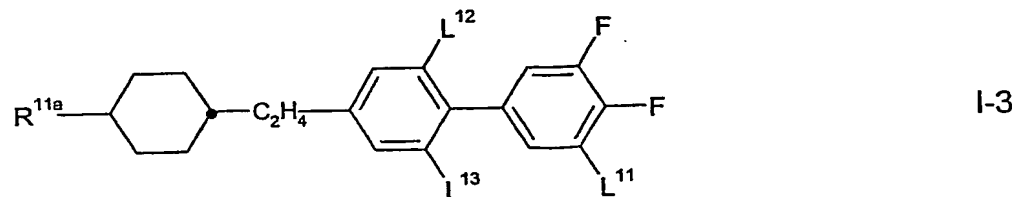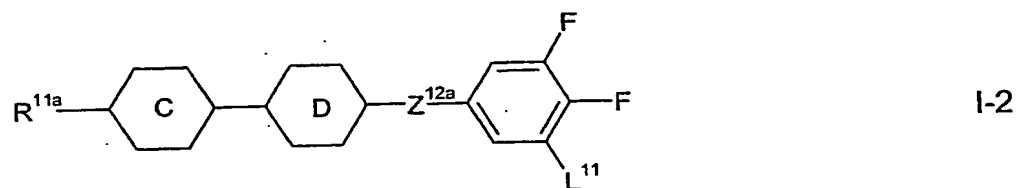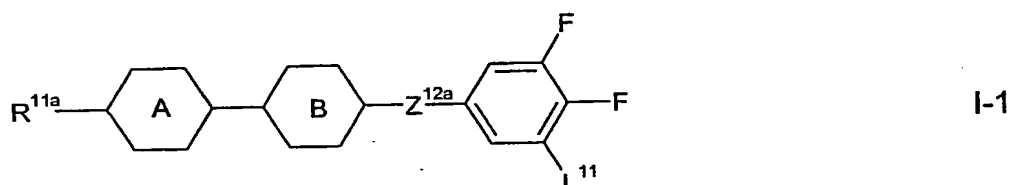
I-3
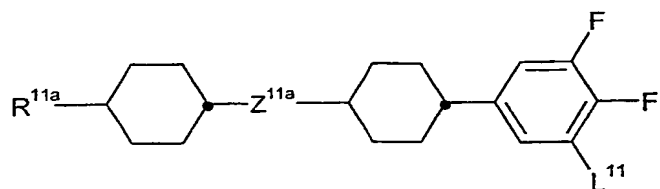
I-4
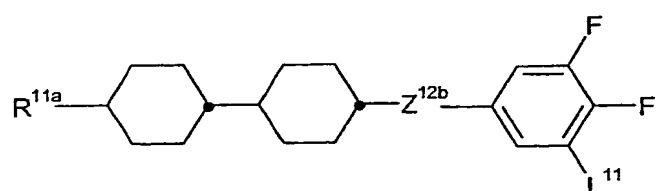
I-5

wherein

R^{11a} is defined as R^{11} in formula I and preferably an unsubstituted and straight-chain or branched alkanyl, alkoxy or alkenyl radical with up to 8 carbon atoms;

Z^{11a} and Z^{12b} are independently of each other $-C_2F_4-$, $-CF=CF-$, $-C_2H_4-$, $-OCH_2-$ or $-CH_2O-$;

Z^{12a} is a single bond, $-CF_2O-$ or $-CO-O-$;

L^{11}, L^{12} and L^{13} are independently of each other H or F;
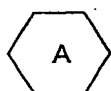
 is a 1,4-phenylene or trans-1,4-cyclohexylene ring;
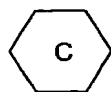
 is a 1,3-dioxan-2,5-diyl or tetrahydropyran-2,5-diyl ring; and
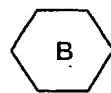
 and are independently of each other ;

 , , , or
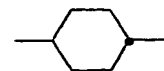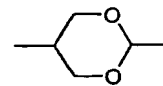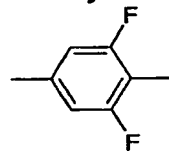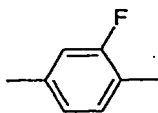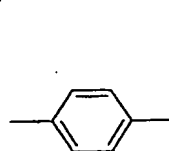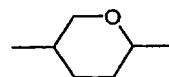
Preferably, compounds of formula I are selected from subformulas I-1 and I-2.

Some specific compounds of preferred compounds of formula I are the
following ones:

5

I-A

10

I-B

15

I-C

20

I-D

I-E

25

I-F

30

I-G

35

I-H

5

I-I

10

I-J
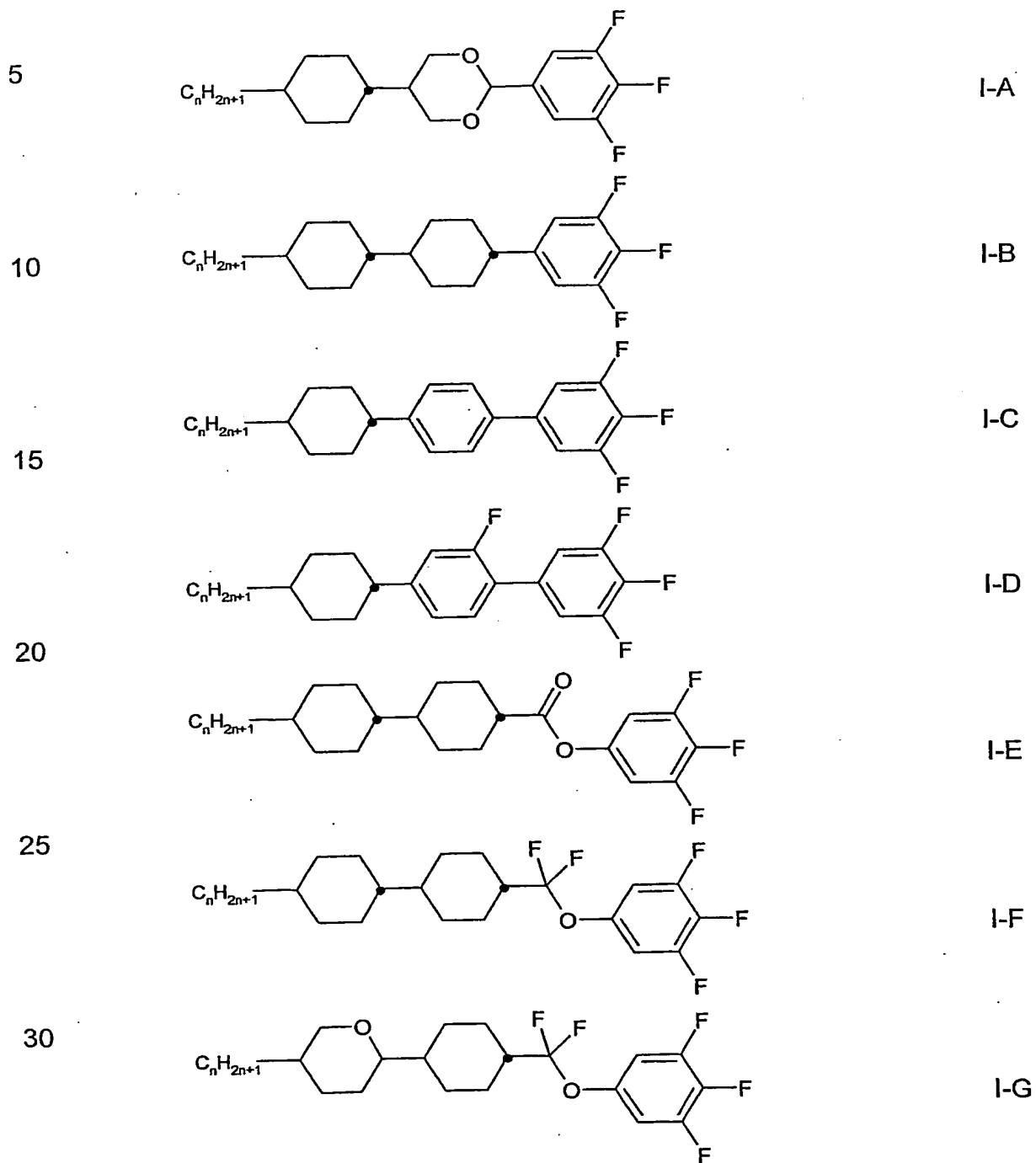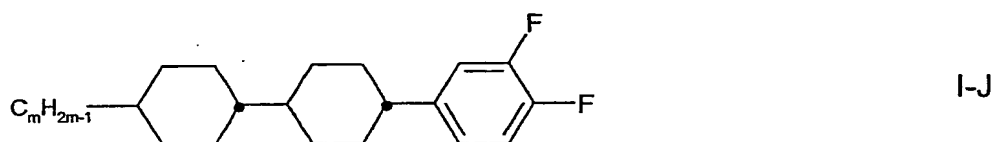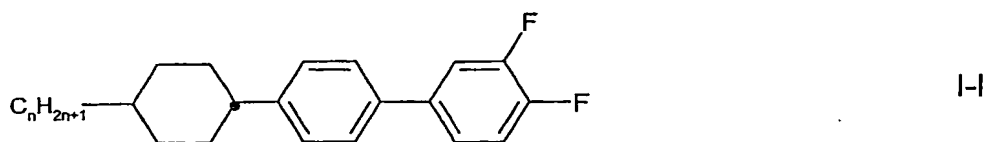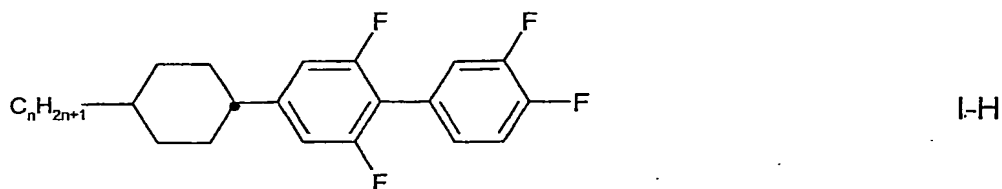
with n and m being independently of each other 2, 3, 4, 5, 6 or 7 and
C_nH_{2n+1}- and C_mH_{2m-1}- both being preferably straight-chain radicals. It is
15   especially preferred that n is 2, 3 and 5, while m is 2 or 3.

While liquid crystal compositions for use in bistable liquid crystal devices of
the invention comprising compounds of the formulas I-A to I-J usually
exhibit values of the birefringence Δn below about 0.11 which in many
20   cases is desirable for reflective and transflective displays, in some other
cases it might be useful to have liquid crystal compositions according to
the present invention that show higher Δn values. In these cases it is
particularly preferred to have compounds of the following formulas
included in component (π):
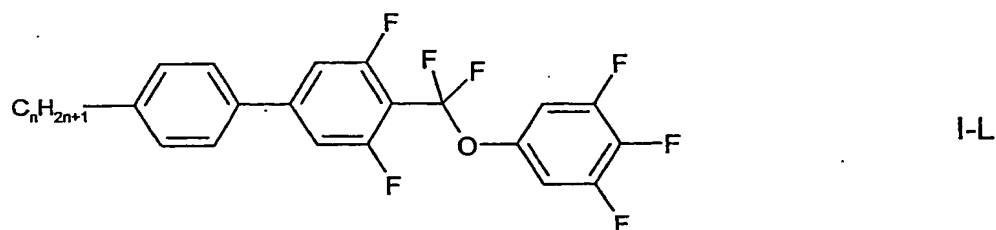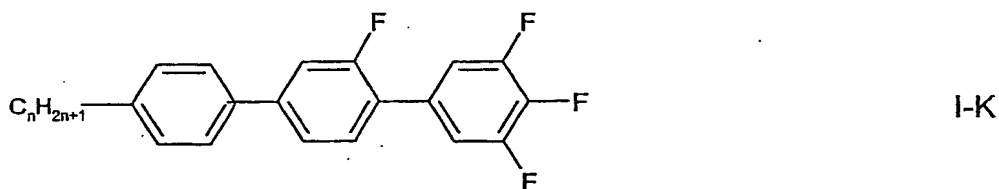
25

I-K

30

I-L

35   with n being 2, 3, 4, 5, 6 or 7 and C_nH_{2n+1}- being preferably a straight-chain
radical. It is especially preferred that n is 2, 3 and 5. It should be noted that

besides these compounds of formulas I-K and I-L other compounds having a terminal phenyl ring of formula A may or may not be contained in component (π).

5   Some further compounds of formula I that may be comprised by component (π) of the liquid crystal composition according to the present invention are:

10

I-M

15

I-N

20

I-O

I-P

25

I-Q

30

I-R

35

I-S

5

I-T

10

I-U

15

I-V

I-W

20

I-X

25

I-Y

30

I-Z
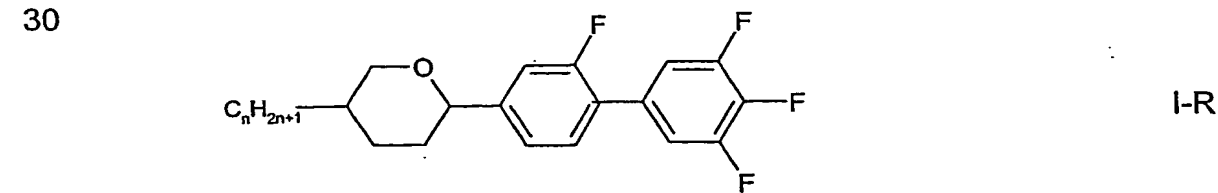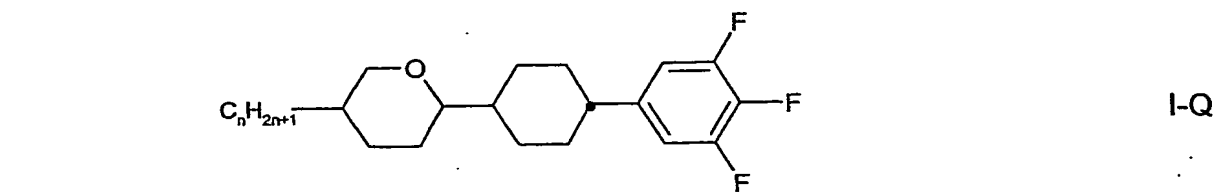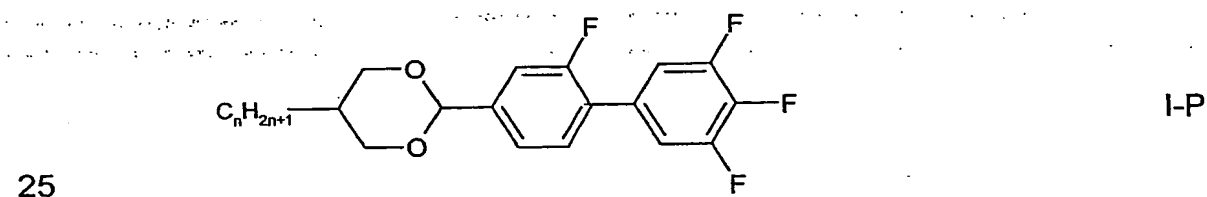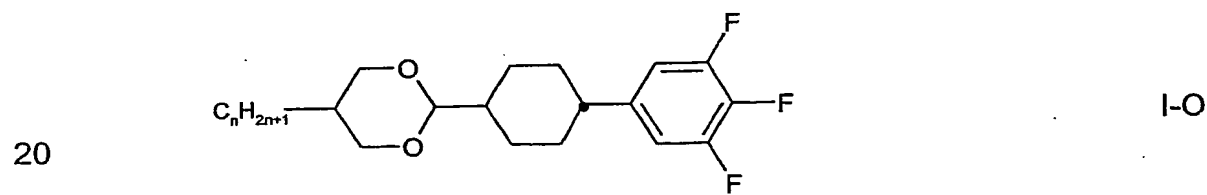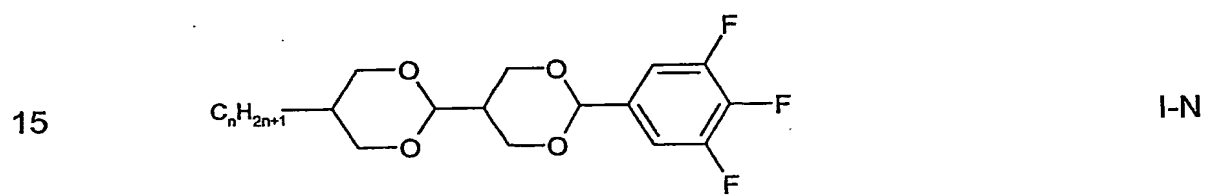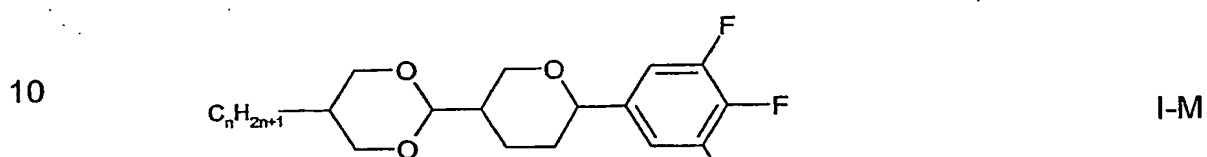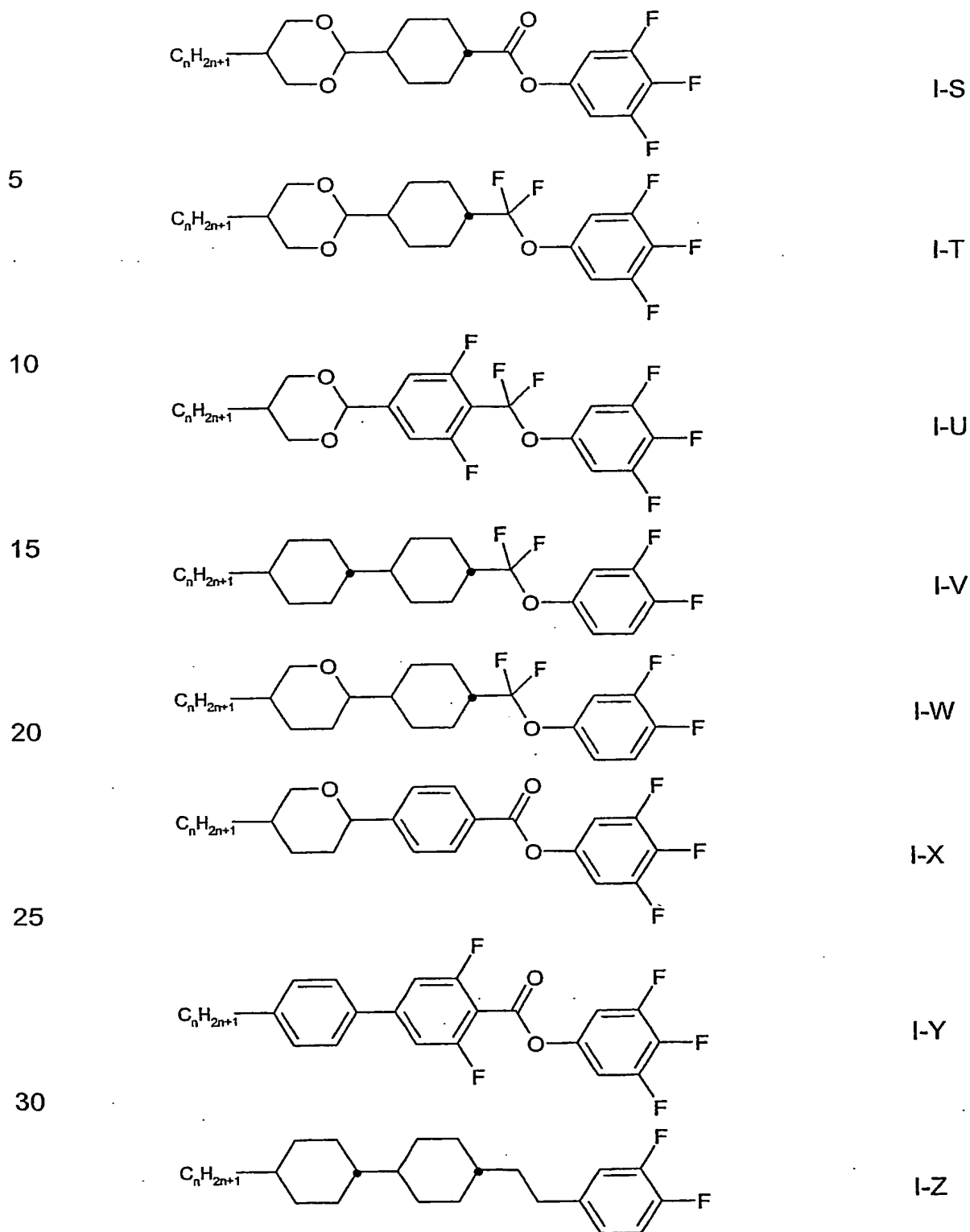
35   with n being 2, 3, 4, 5, 6 or 7 and C_nH_{2n+1}- being preferably a straight-chain radical.
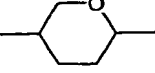
With regard to compounds of formula II it is more preferred that
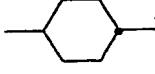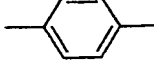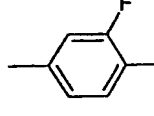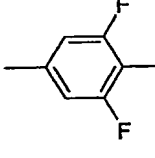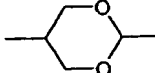
R^{21} is a C_1 to C_8 alkanyl, alkenyl or alkoxy radical unsubstituted or substituted with at least one F atom; especially an unsubstituted and straight-chain alkanyl or alkenyl radical with 2, 3, 4, 5, 6 or 7 carbon atoms;
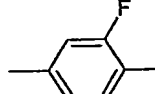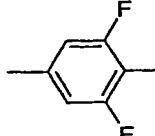
L^{21} is H or F, especially F;

X^{21} is F or Cl, especially F;

Z^{21}, Z^{22} and Z^{23} are each a single bond, $-CF_2O-$ or $-CO-O-$ whereby at least two of Z^{21}, Z^{22} and Z^{23} are each a single bond;

A^{21} is or ;

A^{22} is , , , or

A^{23} is or .

Preferred subformulas of formula II are inter alia:

                                                                 II-1

                                                                 II-2

II-3
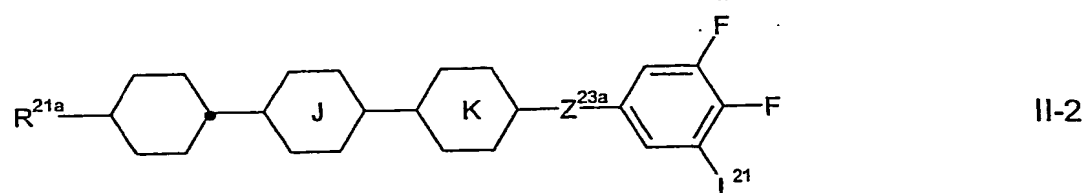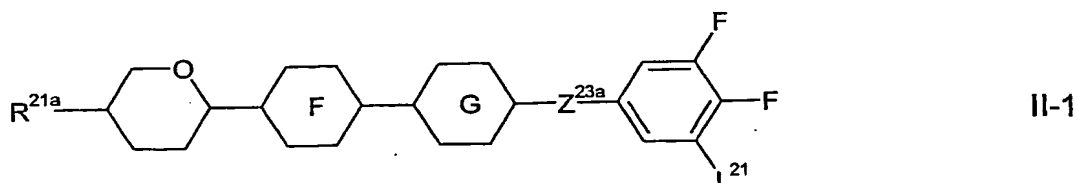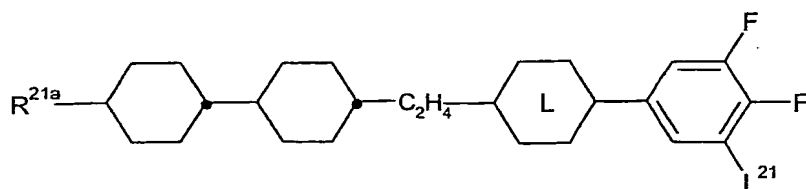
wherein

R^{21a} is defined as R^{21} for formula II above and preferably an unsubstituted and straight-chain or branched alkanyl, alkoxy or alkenyl radical with up to 8 carbon atoms;

Z^{23a} is a single bond, -CF$_2$O- or -CO-O-;

L^{21} is H or F;

  and   are independently of each other ,

;
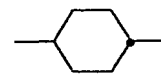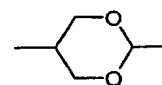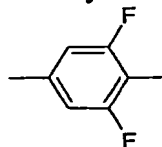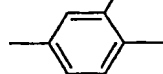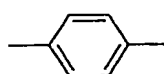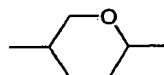
  and   are independently of each other ,
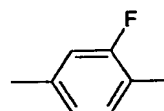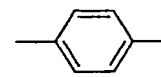
  or   ; and
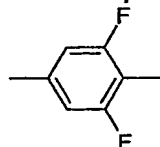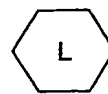
  is , ,   or .
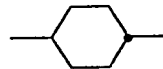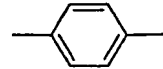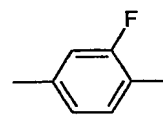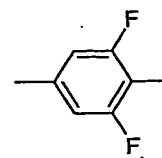
Preferably, compounds of formula II are selected from subformulas II-1 and II-2.

Some specific compounds of preferred compounds of formula II are the following ones:
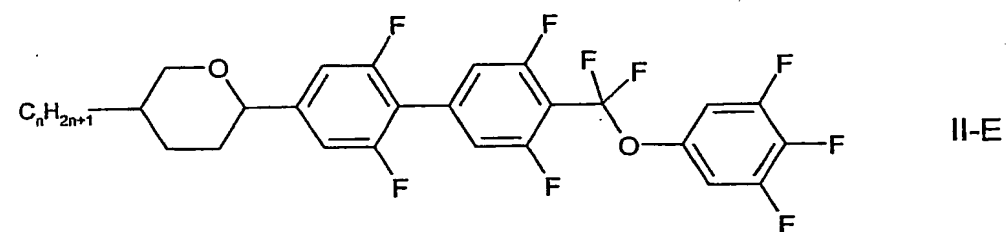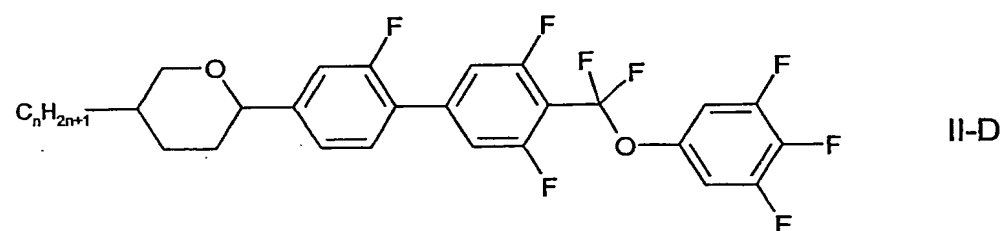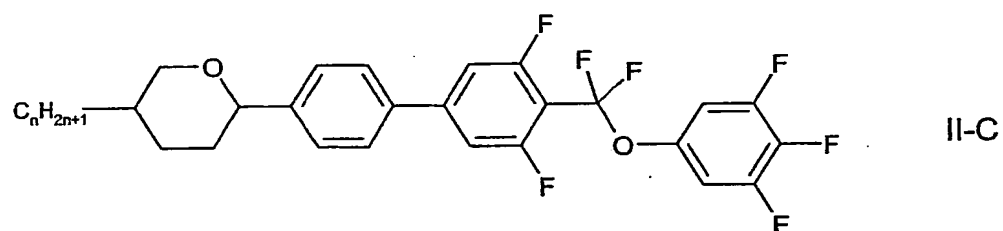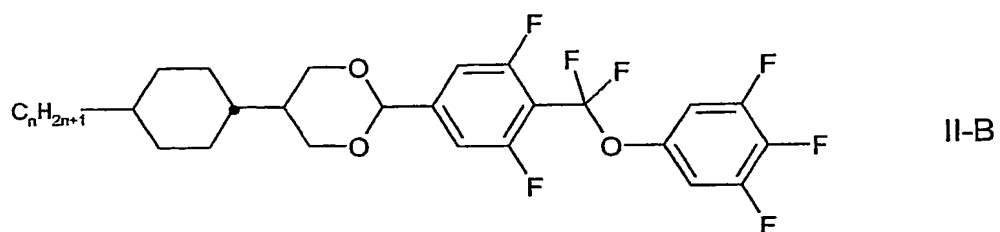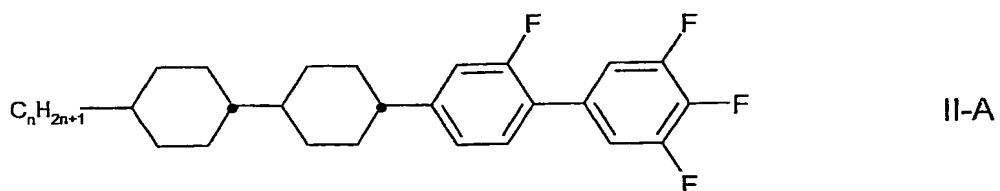
II-A

5

II-B

10

II-C

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II-D

20

II-E

25

with n being 2, 3, 4, 5, 6 or 7 and C_nH_{2n+1}- being preferably a straight-chain radical. It is especially preferred that n is 2, 3 and 5.

30   Some further compounds of formula II that may be comprised by component (π) of the liquid crystal composition according to the present invention are:

35
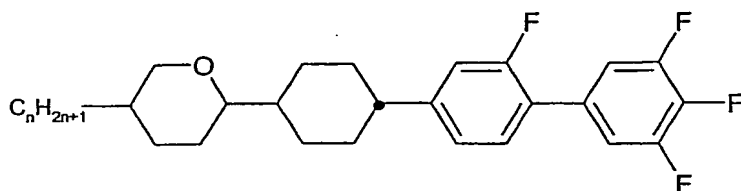
II-F
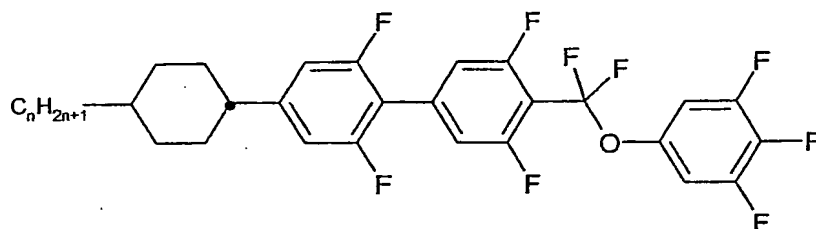
II-G
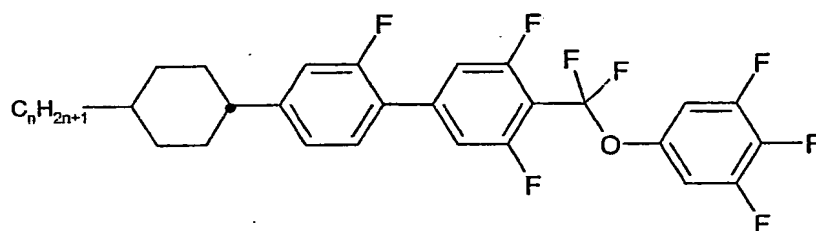
II-H
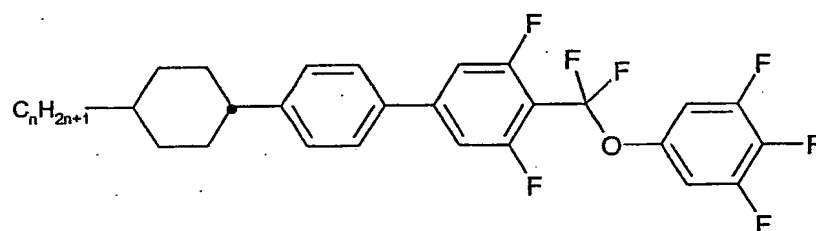
II-I

II-J
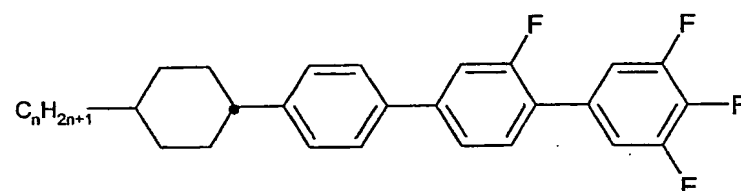
The component (π) of the liquid crystal composition of the instant invention may comprise only compounds of formula I above; in certain embodiments of the invention, however, it comprises only compounds of formula II above. In another group of embodiments of the invention it may comprise compounds of formula I as well as of formula II. In the latter case the weight ratio of compounds of formula I to compounds of formula II is from about 1:10 to about 10:1.

The liquid crystal composition for use in the bistable liquid crystal device according to the invention may comprise further mesogenic or liquid crystalline compounds known in the art. They may be present in order to

M , Q , R and S are

independently of each other or

;

N is or ;

in which

P is or ,

in which

L^{32} and L^{33} are independently of each other H or F.

With respect to formula III it is preferred that a is 1. Preferred compounds of formula III are of the following formulas:

R^{31}— —R^{32} IIIA

R^{31}— —R^{32} IIIB

R^{31}— —R^{32} IIIC

R^{31}— —R^{32} IIID

R^{31}— —R^{32} IIIE

- 34 -

IIIF
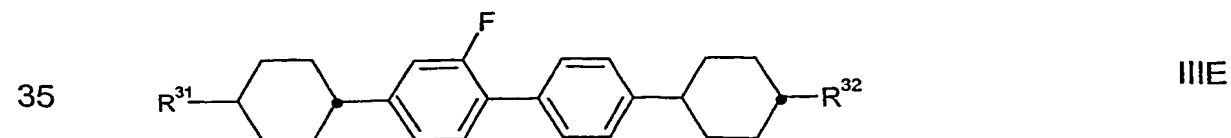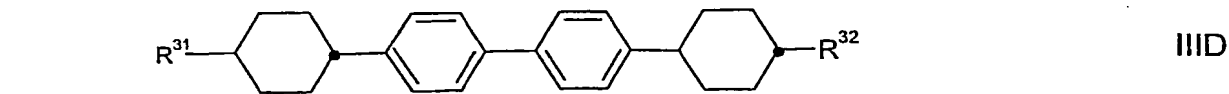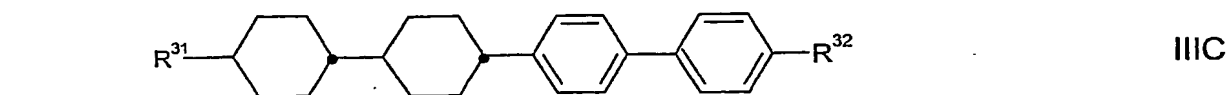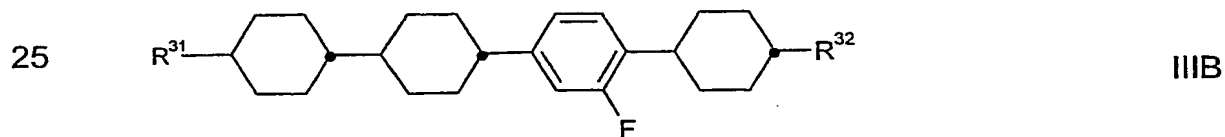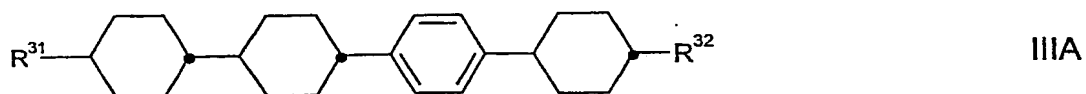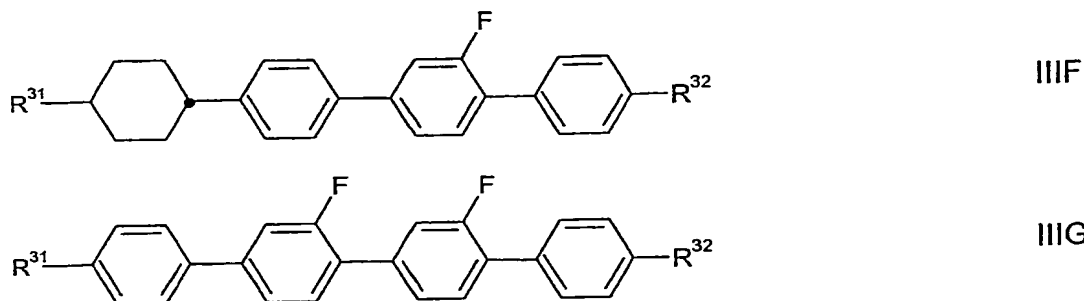
IIIG

with R^{31} and R^{32} being as defined above. Preferably, in formulas III and IIIA to IIIG R^{31} and R^{32} are both independently of each other straight-chain alkyl, more preferred straight-chain alkanyl or alkenyl having 2, 3, 4, 5 or 6 carbon atoms, especially straight-chain alkanyl with 2 to 6 carbon atoms, a is 1 and L^{31} is H or F (for formula III). Highly preferred compounds are of formula IIID and IIIE. Especially preferred examples of formula III are compounds of formula III1 to III6:

III1

III2

III3

III4

III5
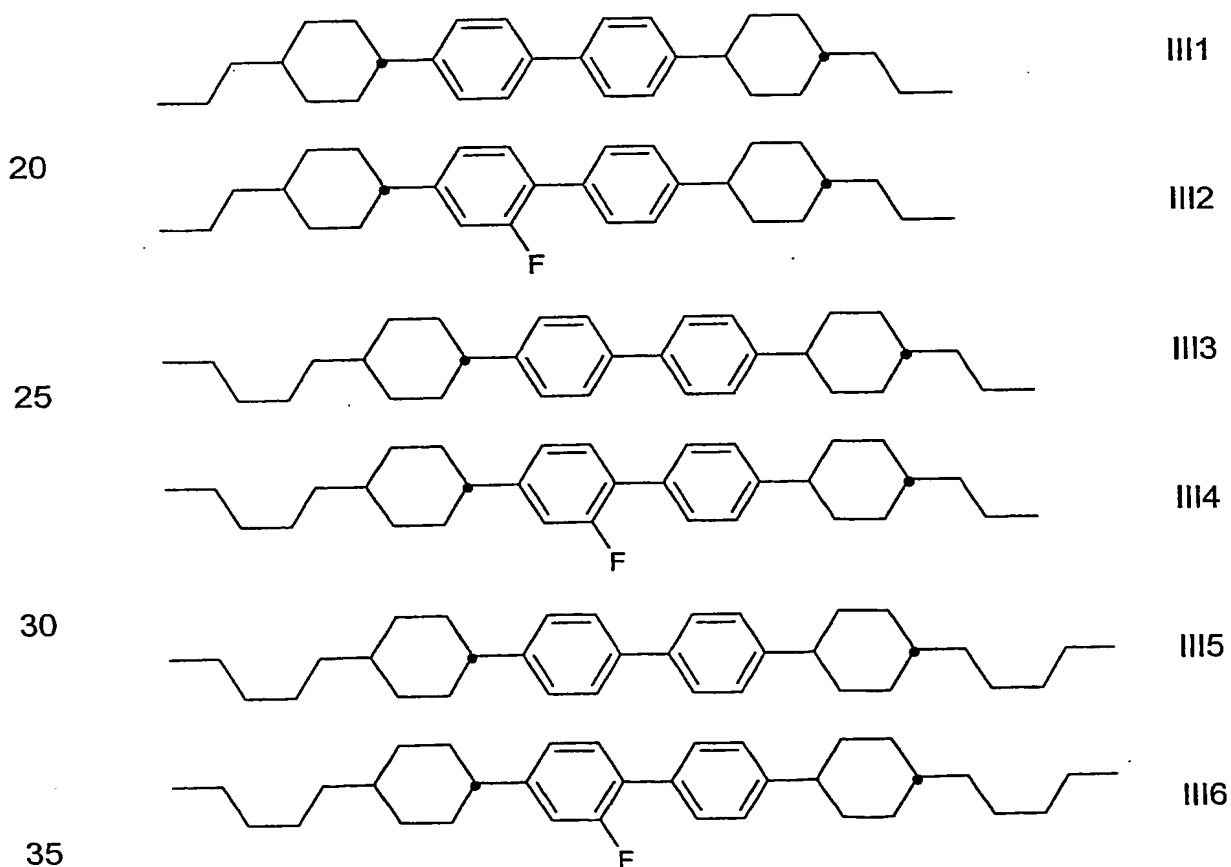
III6

Most preferred compounds of formula III are compounds III2, III4 and III6, and it is especially preferred to have a mixture of all three compounds in the liquid crystal composition.

5

In some embodiments of the present invention it may also be preferred that a in formula III is zero. Then, preferred compounds of formula III are of the following formulas:

10

R^{31}—⬡—⬡—⬡—R^{32} IIIH

R^{31}—⬡—⬡—⬡—R^{32}
                    |
                    F   IIIJ

15
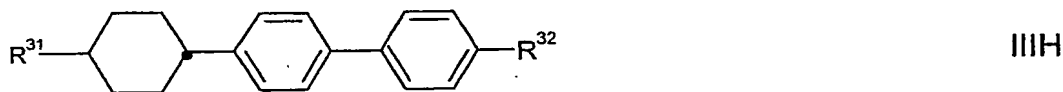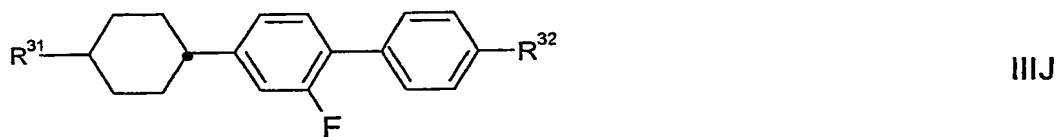
whereby R^{31} and R^{32} are as defined above and preferably independently of each other straight-chain alkyl, more preferred straight-chain alkanyl or alkenyl having 2, 3, 4, 5 or 6 carbon atoms, even more preferred straight-chain alkanyl with 2 to 6 carbon atoms. Especially, R^{31} is n-propyl or n-
20   pentyl and R^{32} is ethyl.

Preferred compounds of formula IV are of the following compounds:

25   R^{41}—⬡—⬡—Z^{41}—⬡—⬡—R^{42} IV-A

R^{41}—⬡—⬡—Z^{41}—⬡—⬡—R^{42} IV-B

30   R^{41}—⬡—Z^{41}—⬡—⬡—R^{42} IV-C

R^{41}—⬡—Z^{41}—⬡—⬡—R^{42} IV-D

35

- 36 -
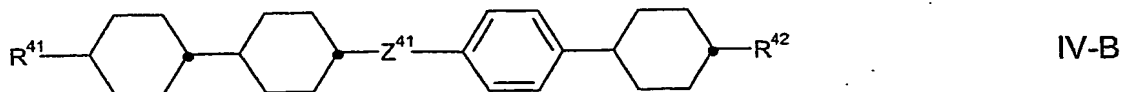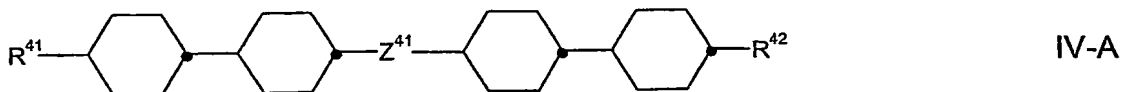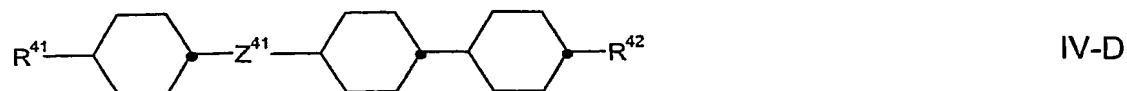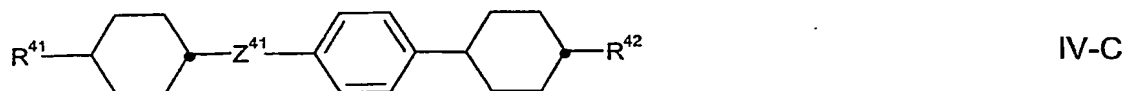
with R^{41}, R^{42} and Z^{41} being as defined above; Z^{41} is preferably -CO-O- or, in case of formula IVD, -OCH$_2$-. R^{41} and R^{42} are both independently of each other straight-chain alkyl, more preferred straight-chain alkanyl or alkenyl having 2, 3, 4, 5 or 6 carbon atoms, especially straight-chain alkanyl with 2 to 6 carbon atoms. Compounds of formula IVB are more preferred. Especially preferred examples of formula IV are compounds of formulas IV1 to IV3 as well as of formulas IV4 and IV5 and of formulas IV6 to IV8:

IV1

IV2

IV3

IV4
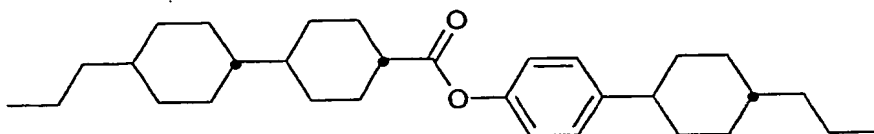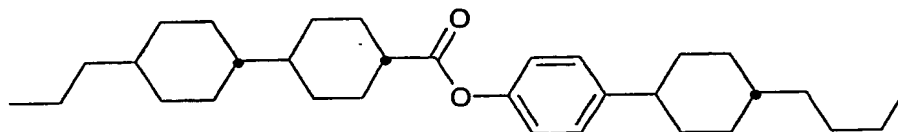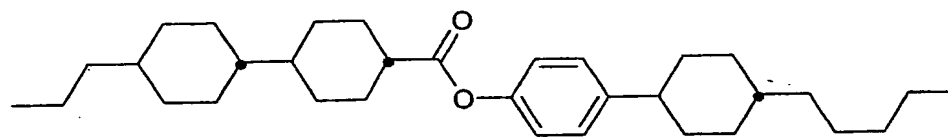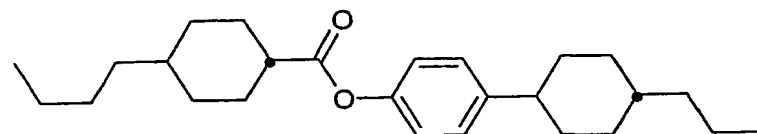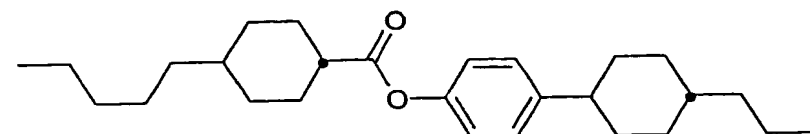
IV5
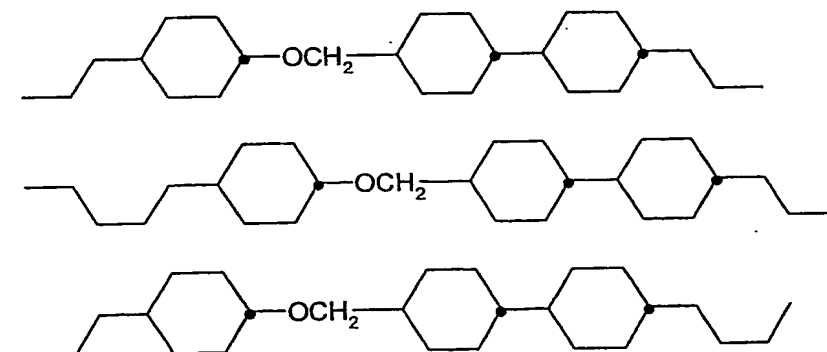
IV6
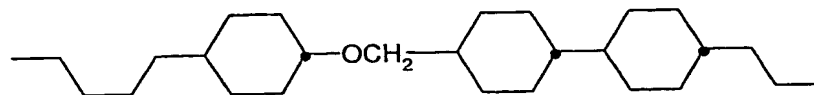
IV7
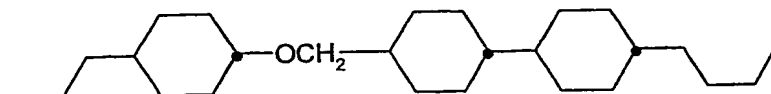
IV8

It is especially preferred to have a mixture of compounds IV1, IV2 and IV3 in the liquid crystal composition.

5 Preferably, in formula V above R^{51} is straight-chain alkyl, more preferred straight-chain alkanyl or alkenyl having 2, 3, 4, 5 or 6 carbon atoms, especially straight-chain alkanyl with 2 to 6 carbon atoms, and R^{52} is straight-chain alkyl or, more preferred, alkoxy having 1, 2, 3 or 4 carbon atoms. Especially preferred examples of formula V are compounds of
10 formula V1 to V6:
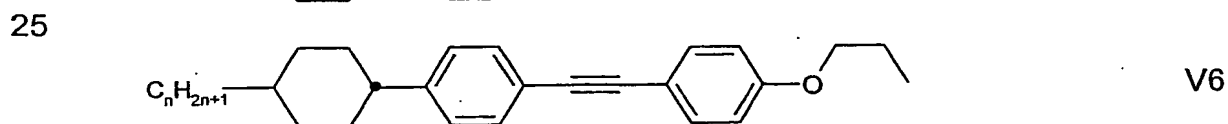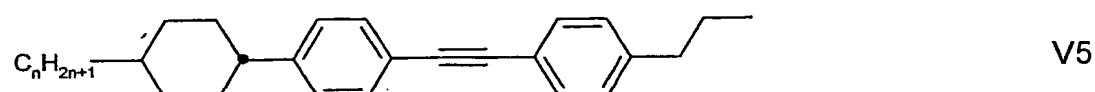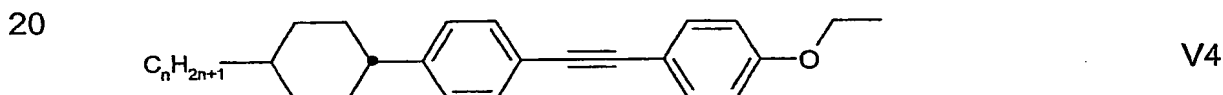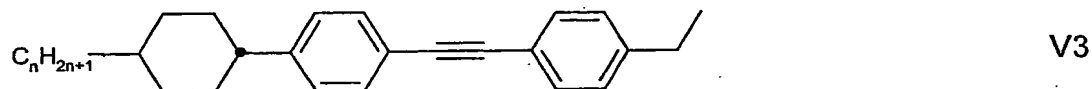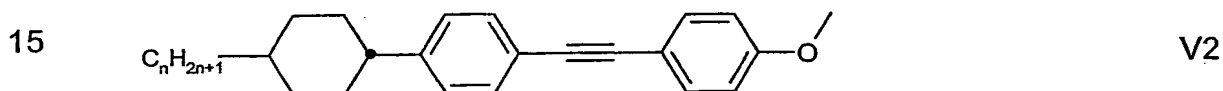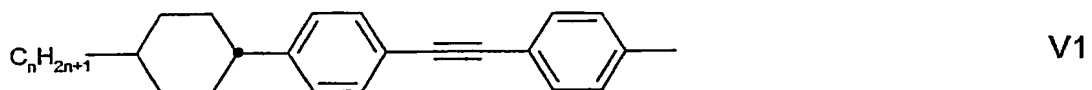
30 in which n is an integer from 1 to 6, preferably 2, 3 or 4, especially 3. Preferred compounds of formula V are compounds of formula V2, V4 and V6 with n = 3 (giving an n-propyl substituent). It is preferred to have a mixture of all three compounds V2, V4 and V6 in the liquid crystal composition.

35

Preferably, in formula VI above R^{61} is straight-chain alkanyl or alkenyl, especially with 2, 3, 4 or 5 carbon atoms, and R^{62} is straight-chain alkanyl or alkoxy both having 1, 2, 3, 4 or 5 carbon atoms. Especially preferred are compounds of formula VIA or VIB with m = 2, 3, 4, 5 and n = 1, 2, 3, 4, 5.

5

C_mH_{2m-1}—⬡—CH=CH—⬡—⬡—C_nH_{2n+1} VIA

C_mH_{2m-1}—⬡—CH=CH—⬡—⬡—OC_nH_{2n+1} VIB
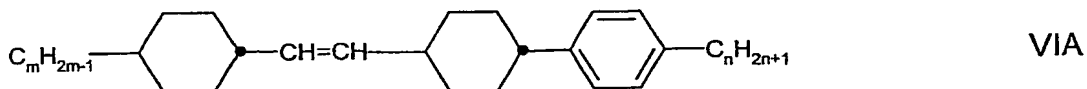
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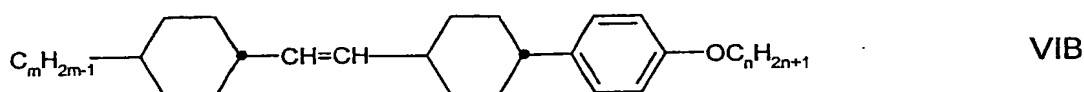
Preferred compounds of formula VI are compounds of formula VI1 to VI4:

15

                                                  VI1

                                                  VI2

20

                                                  VI3

25

                                                  VI4
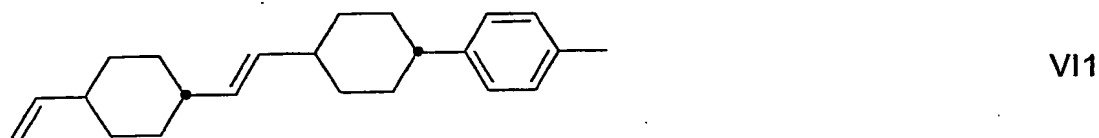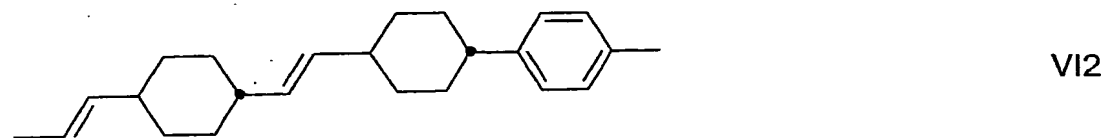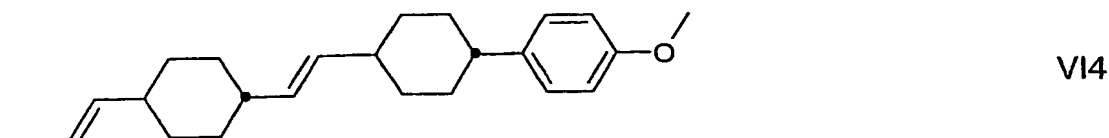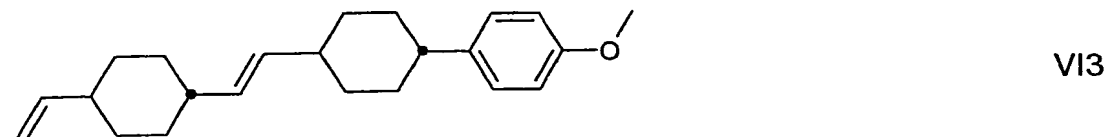
30   Especially preferred are compounds of formula VI1, VI3 and VI4. They may be used alone or, more preferred, as a mixture of two or three compounds.

        Regarding compounds of formula VII specific compounds are of the
35   following formulas

- 39 -

R^{71}—⬡—⬡—CO$_2$—⬡—R^{72} VIIA

R^{71}—⬡—⬡—CO$_2$—⬡—R^{72} VIIB

R^{71}—⬡—⬡—CO$_2$—⬡—R^{72} VIIC

R^{71}—⬡—⬡—CO$_2$—⬡—R^{72} VIID
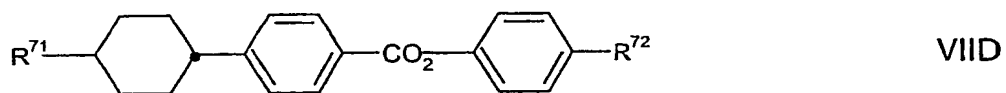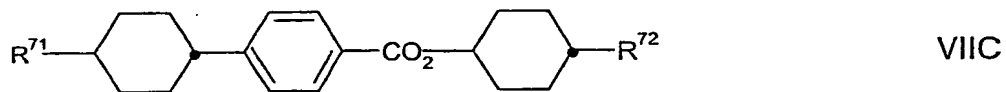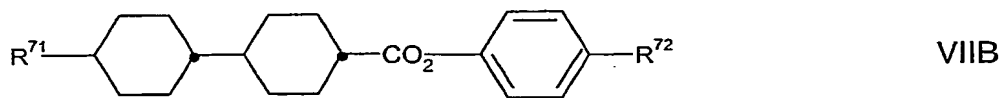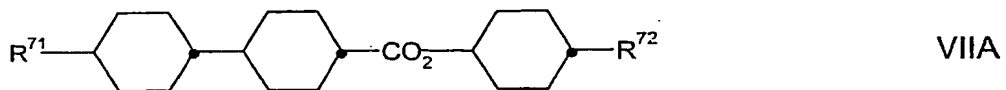
with R^{71} and R^{72} being as defined above. Preferably, R^{71} and R^{72} are straight-chain alkyl, especially alkanyl, with 1, 2, 3, 4, 5 or 6 carbon atoms. Preferred compounds of formula VII are:

C$_n$H$_{2n+1}$—⬡—⬡—CO$_2$—⬡—C$_m$H$_{2m+1}$ VIIC1

C$_n$H$_{2n+1}$—⬡—⬡—CO$_2$—⬡—C$_m$H$_{2m+1}$ VIID1
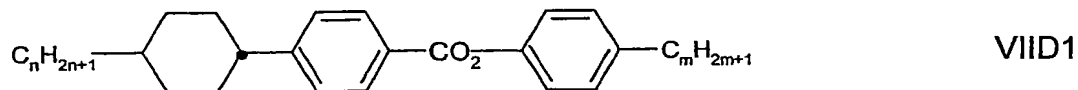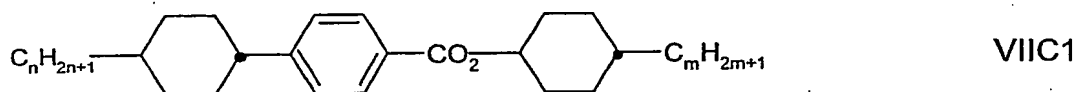
with n and m being independently of each other 1, 2, 3, 4, 5 or 6. Especially preferred examples of compounds of formula VII are

⬡—⬡—CO$_2$—⬡   VII-1

⬡—⬡—CO$_2$—⬡   VII-2

⬡—⬡—CO$_2$—⬡   VII-3
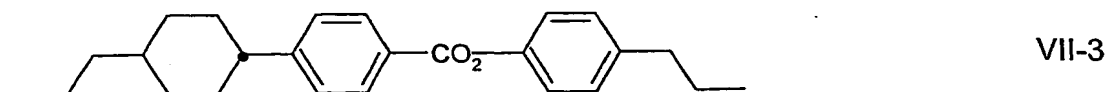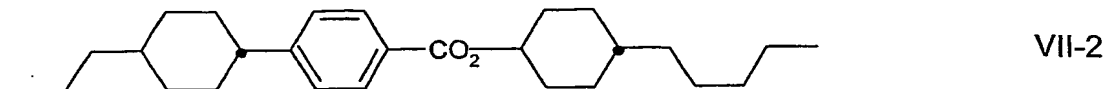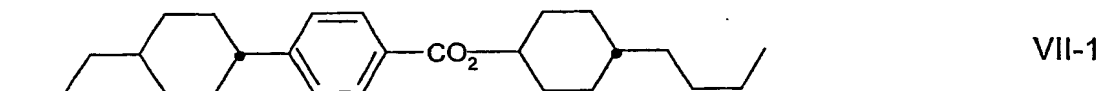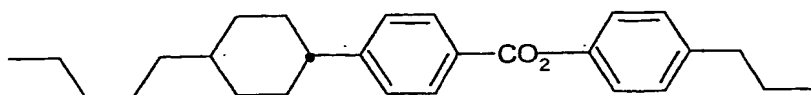
VII-4

Regarding compounds of formula VIII specific compounds are of the following formulas

R^{81}—⬡—⬡—⬡—R^{82} VIIIA
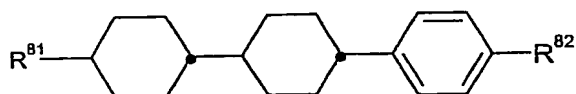
Preferably, in formula VIII R^{81} is straight-chain alkanyl or alkenyl, especially having 2, 3, 4 or 5 carbon atoms, and R^{82} is straight-chain alkanyl having 1, 2, 3, 4 or 5 carbon atoms (formula VIIIA or VIIIB with m = 2, 3, 4, 5, n = 1, 2, 3, 4, 5, and p = 1, 2, 3, 4, 5)..

C_pH_{2p+1}—⬡—⬡—⬡—C_nH_{2n+1} VIIIA

C_mH_{2m-1}—⬡—⬡—⬡—C_nH_{2n+1} VIIIB
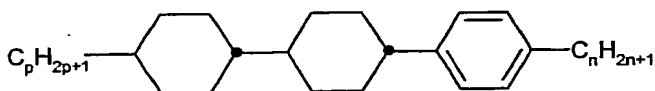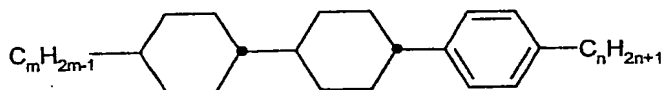
Especially preferred examples of compounds of formula VIII are
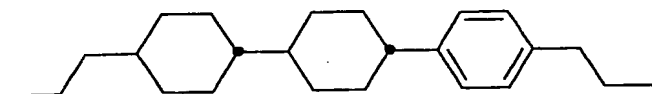
VIII-1
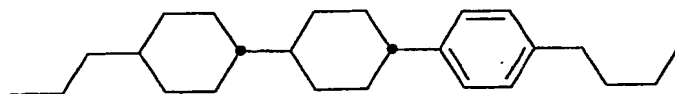
VIII-2
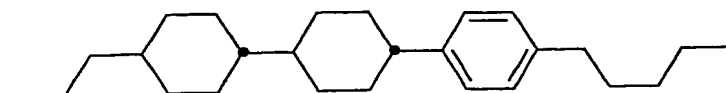
VIII-3
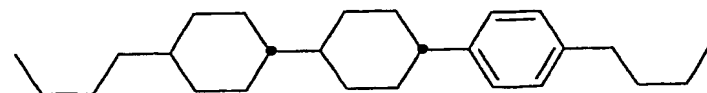
VIII-4
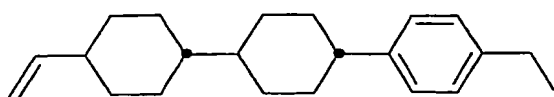
VIII-5
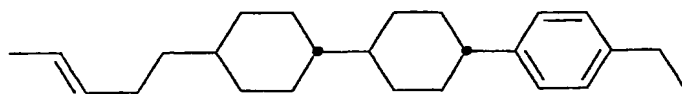
VIII-6
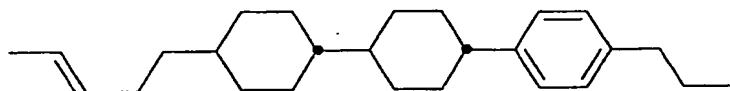
VIII-7
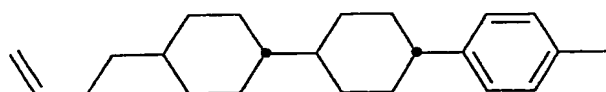
VIII-8

Compounds of formula III to VIII are usually used in the liquid crystal composition according to the invention in a total amount of up to 40 weight%, preferably in a total amount of 0 to about 20 weight%, more preferably in a total amount of about 2 to about 18 weight% and especially in a total amount of about 3 to about 15 weight%. Compounds of each formula III to VIII may be present in a single composition although it is preferred that compounds of only one, two or three different of these formulas are contained in a specific liquid crystal mixture of the present invention. For instance, in a specific composition there might be only compounds of formulas III and IV or of formulas V and VI and so on. It is, however, especially preferred that compounds of only one of these formulas III to VIII are present in a single specific composition according to the invention.

The liquid crystal composition according to the invention may also comprise compounds of the following formulas:

R^{91}—T—U—R^{92} IX

R^{101}—◯—≡—◯—R^{102} X

R^{111}—◯—◯—◯—Y^{111} XI
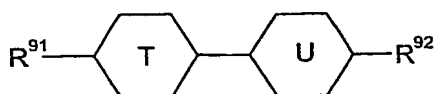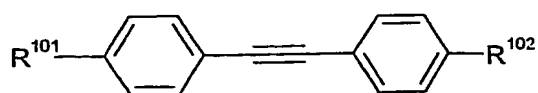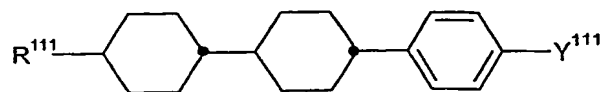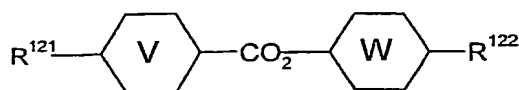
$$R^{121} \longleftarrow \boxed{V} \longrightarrow CO_2 \longleftarrow \boxed{W} \longrightarrow R^{122} \qquad \text{XII}$$

in which

$R^{91}, R^{92}, R^{101}, R^{102}, R^{111}, R^{121}$ and R^{122}

> are independently of each other C_1-C_{15} alkyl which is unsubstituted or mono- or poly-substituted with halogen and in which one or more of the CH_2 groups may be replaced independently of each other by -O-, -S-, -CH=CH-, -C≡C-, -CO-O-, -OC-O- such that there are no hetero atoms directly linked to each other; preferably these radicals are independently of each other straight-chain alkanyl, alkenyl or alkoxy radicals with up to 8 carbon atoms;

Y^{111} is C_1-C_{15} alkanyl or C_2-C_{15} alkenyl that are independently of each other mono- or poly-substituted with halogen, or C_1-C_{15} alkoxy which is mono- or poly-substituted with halogen; preferably it is an alkanyl or an alkoxy radical with up to 8 carbon atoms in which each of the hydrogen atoms are replaced by F; and

$\boxed{T}$, $\boxed{U}$, $\boxed{V}$ and $\boxed{W}$ are
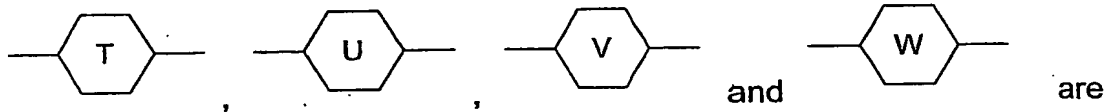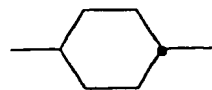
independently of each other $\boxed{}$ or

$\boxed{}$.
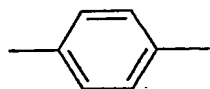
Preferred compounds of formula IX are compounds of the following formulas:

$$C_nH_{2n+1} \longleftarrow \boxed{} \boxed{} \longrightarrow C_pH_{2p+1} \qquad \text{IXA}$$

IXB

IXC

5

IXD

10

IXE

IXF

15

IXG

IXH

20

IXI

IXJ

25
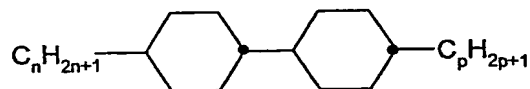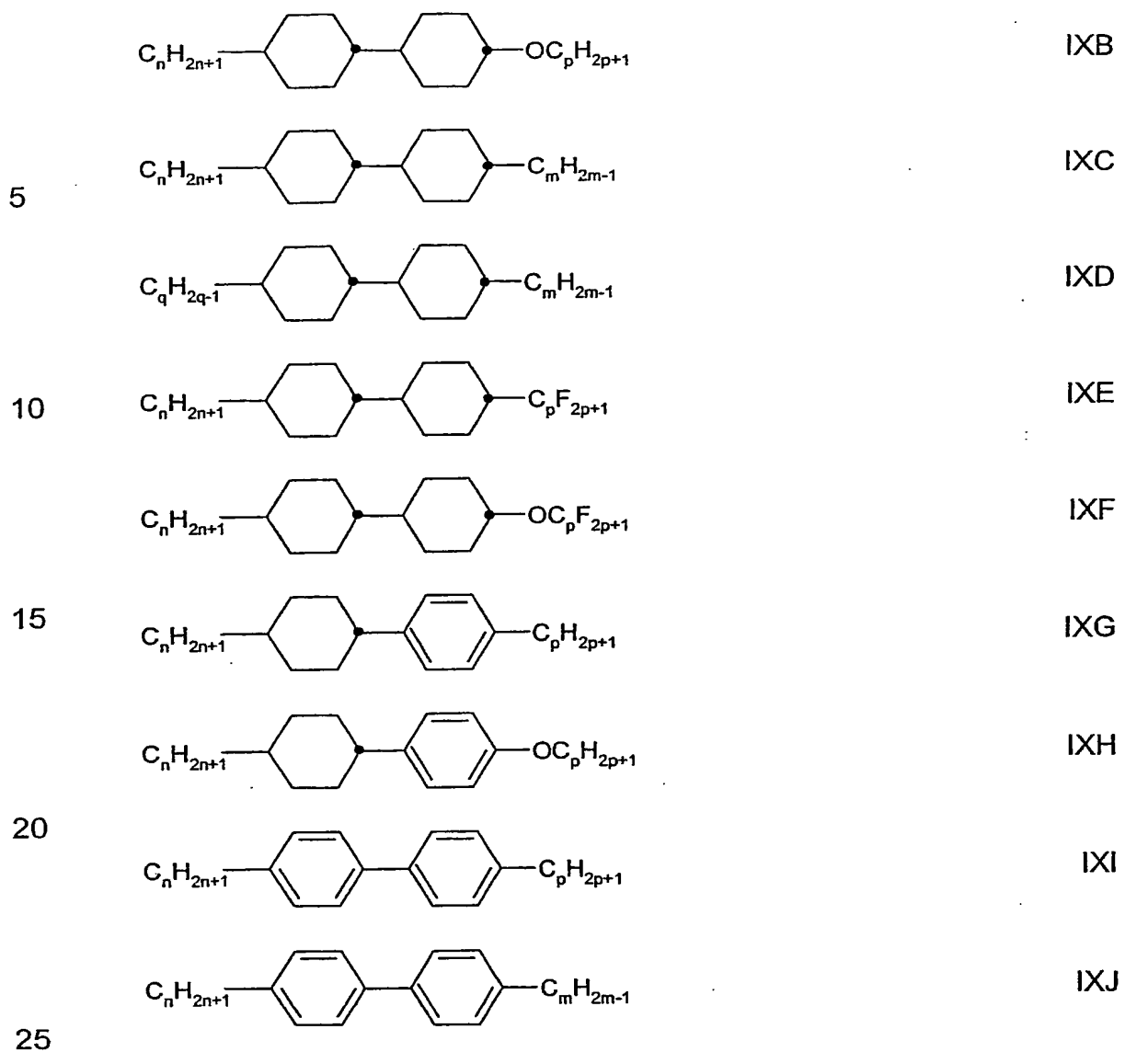
in which n and p are independently of each other an integer from 1 to 8, preferably 2, 3, 4, 5 or 6, and m and q are independently of each other an integer from 2 to 8, preferably 2, 3, 4, 5 or 6.

30

Preferred examples of compounds of formula IX are:

IX1

35

- 44 -

IX2

IX3

IX4

IX5
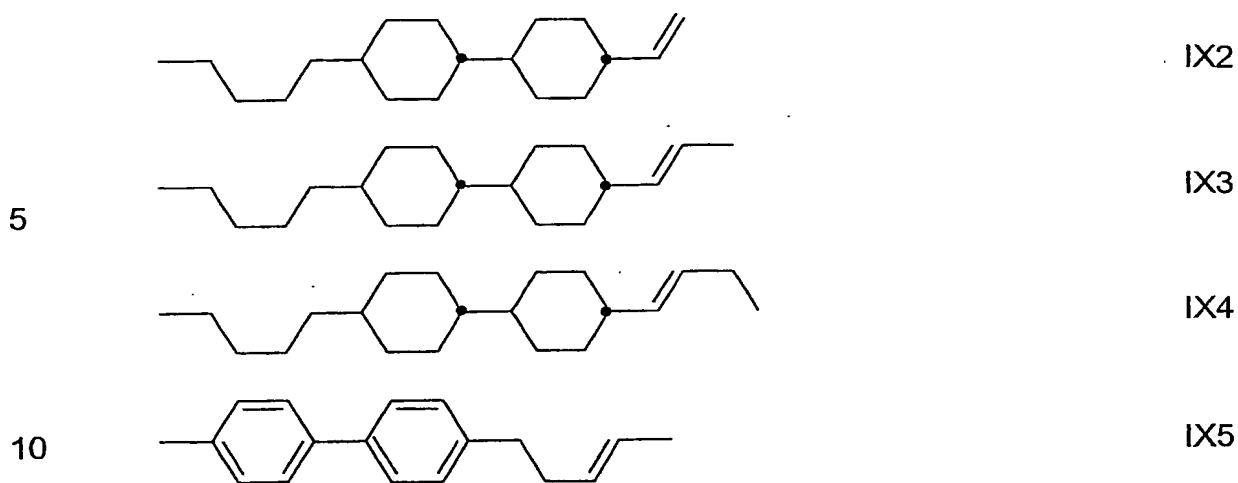
Preferred compounds of formula X are compounds of the following formulas:

$$C_nH_{2n+1} \text{—} \langle \text{ring} \rangle \text{—} \equiv \text{—} \langle \text{ring} \rangle \text{—} C_pH_{2p+1}$$

XA

$$C_nH_{2n+1} \text{—} \langle \text{ring} \rangle \text{—} \equiv \text{—} \langle \text{ring} \rangle \text{—} OC_pH_{2p+1}$$
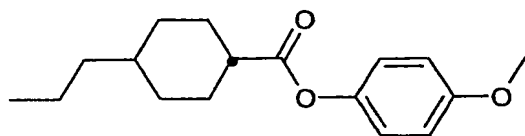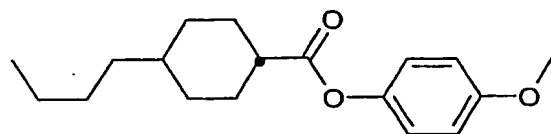
XB
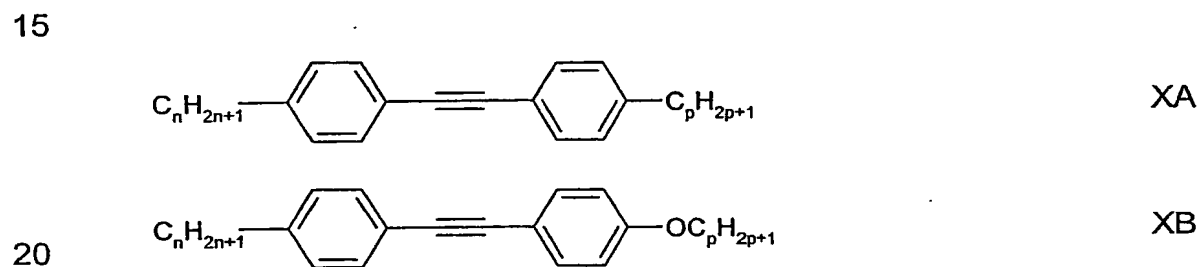
with n being 1, 2, 3, 4, 5, 6, 7 or 8 and p being 1, 2, 3, 4, 5 or 6. Preferred examples of compounds of formula X are the following compounds:
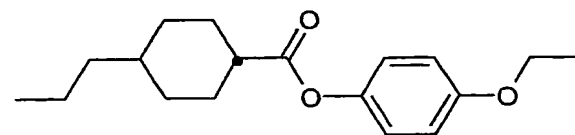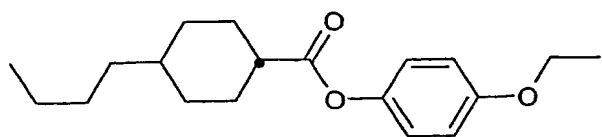
X1

X2

X3

X4

- 45 -

X5

X6
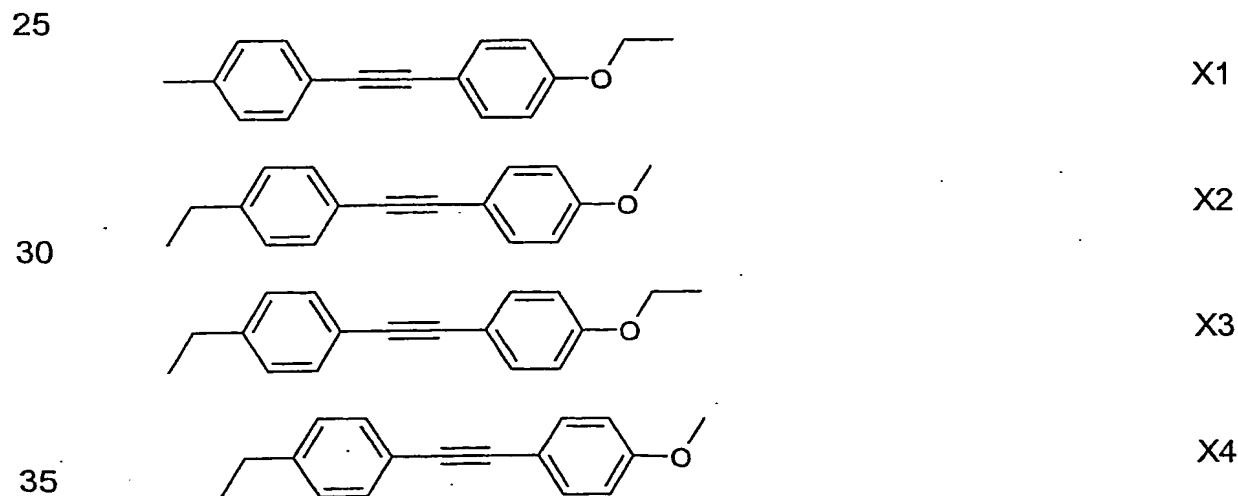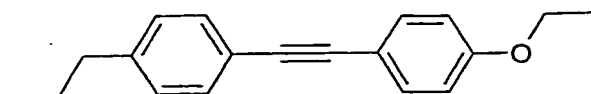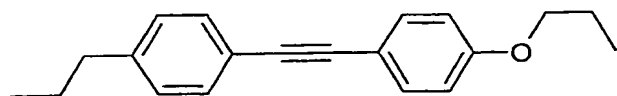
Preferred compounds of formula XI are compounds of the following formulas:

C_nH_{2n+1}—〔cyclohexyl〕—〔cyclohexyl〕—〔phenyl〕—Y^{111} XIA

C_mH_{2m-1}—〔cyclohexyl〕—〔cyclohexyl〕—〔phenyl〕—Y^{111} XIB
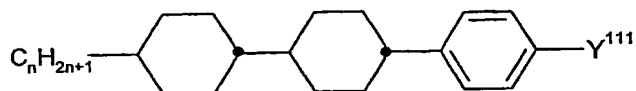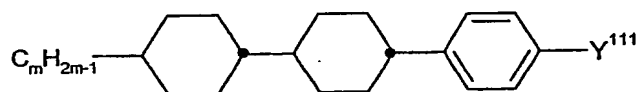
with n being 1, 2, 3, 4, 5 or 6, m being 2, 3, 4, 5 or 6, and Y^{111} being preferably selected from CF_3 and OCF_3. Preferred compounds of formula XI are the following compounds:

〔propyl〕—〔cyclohexyl〕—〔cyclohexyl〕—〔phenyl〕—CF_3 XI1

〔propyl〕—〔cyclohexyl〕—〔cyclohexyl〕—〔phenyl〕—OCF_3 XI2

〔propenyl〕—〔cyclohexyl〕—〔cyclohexyl〕—〔phenyl〕—CF_3 XI3

〔butenyl〕—〔cyclohexyl〕—〔cyclohexyl〕—〔phenyl〕—OCF_3 XI4
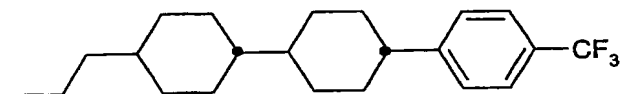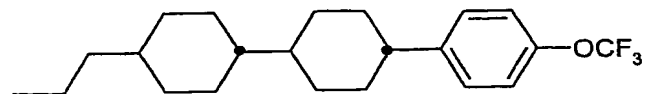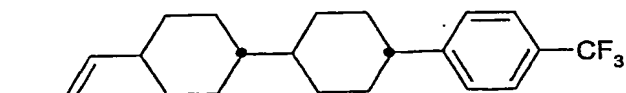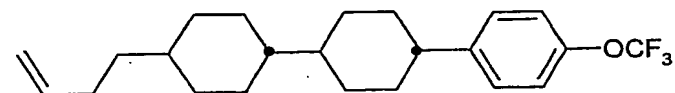
Preferred compounds of formula XII are compounds of the following formulas:
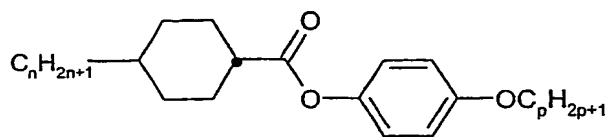
XIIA

5
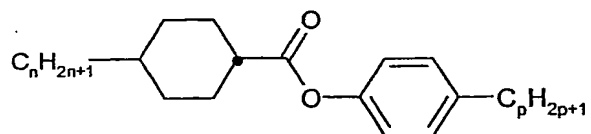
XIIB

10
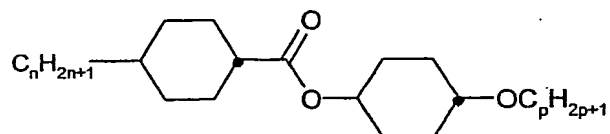
XIIC
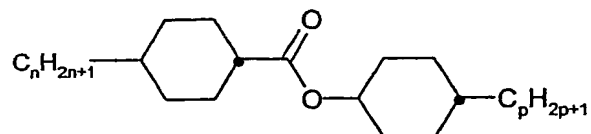
XIID

15
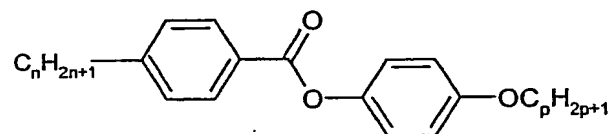
XIIE

20
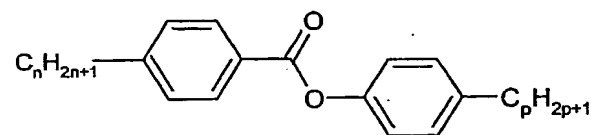
XIIF

with n being 1, 2, 3, 4, 5 or 6 and p being 1, 2, 3, 4, 5 or 6. Specific

25   examples of compounds of formula XII are the following compounds:

XII1

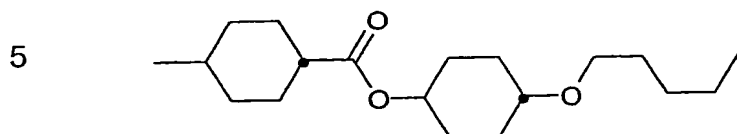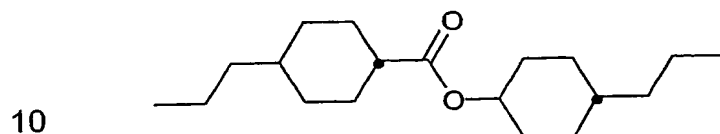30

XII2

XII3

35

XII4

5   XII5
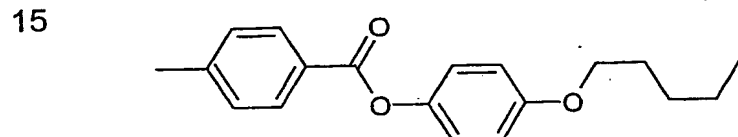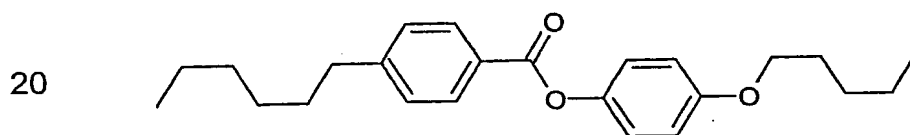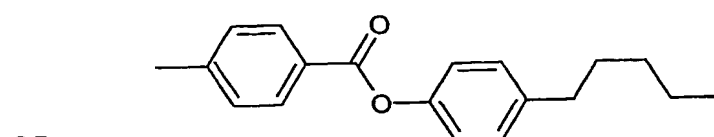

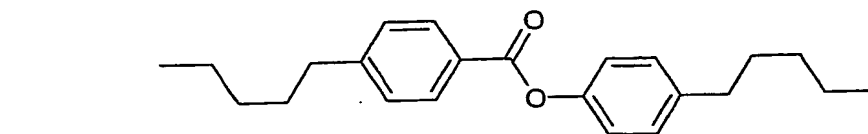   XII6

10

                                                                           XII7

15

                                                                           XII8

20   XII9


                                                                           XII10

25

                                                                           XII11

30
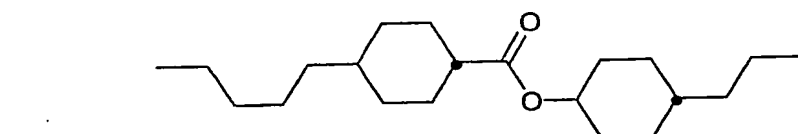
Compounds of formula IX to XII are usually used in the liquid crystal composition according to the invention in a total amount of up to 40 weight%, preferably in a total amount of 0 to about 20 weight%, more preferably in a total amount of about 2 to about 18 weight% and especially

35   in a total amount of about 3 to about 15 weight%. Compounds of each formula IX to XII may be present in a single composition although it is

preferred that compounds of only one, two or three different of these formulas are contained in a specific liquid crystal mixture of the present invention. For instance, in a specific composition there might be only compounds of formulas IX and X or of formulas XI and XII and so on. It is,

5   however, especially preferred that compounds of only one of these formulas IX to XII are present in a single specific composition according to the invention.

The liquid crystal composition according to the invention may also

10   comprise compounds of the following formulas:

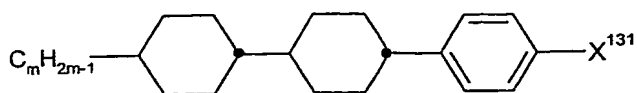XIII

XIV
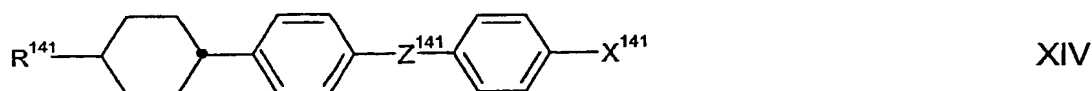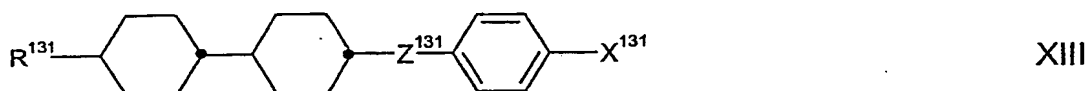
in which

R^{131} and R^{141} are independently of each other C_1-C_{15} alkyl which is

20   unsubstituted or mono- or poly-substituted with halogen and in which one or more of the CH_2 groups may be replaced independently of each other by -O-, -S-, -CH=CH-, -C≡C-, -CO-O-, -OC-O- such that there are no hetero atoms directly linked to each other; preferably these radicals are

25   independently of each other straight-chain alkanyl, alkenyl or alkoxy radicals with up to 8 carbon atoms;

X^{131} and X^{141} are independently of each other F or Cl, preferably F; and

Z^{131} and Z^{141} are independently of each other a single bond, -CF$_2$O- or -CO-O-, preferably a single bond.
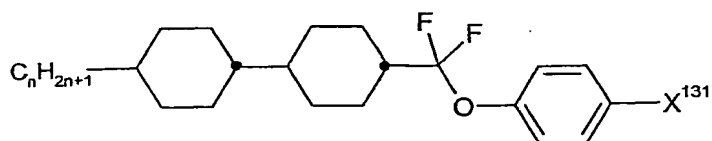
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Preferred compounds of formula XIII are compounds of the following formulas:
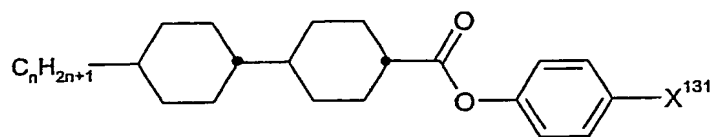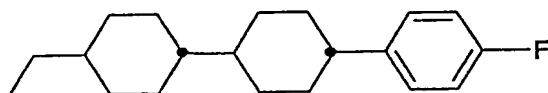

XIIIA

35
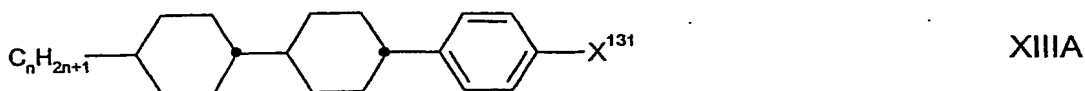
- 49 -

XIIIB

XIIIC
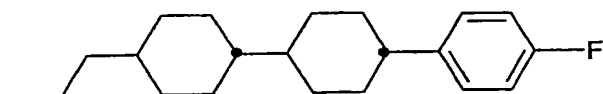

XIIID
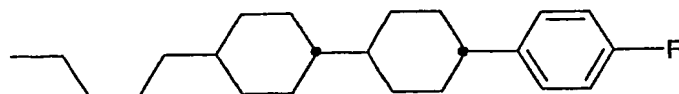
with n being 1, 2, 3, 4, 5, 6, 7 or 8, preferably 2, 3, 4, 5, m being 2, 3, 4, 5, 6, 7, 8, preferably 2, 3, 4, 5, and X^{131} being F or Cl, preferably F. Preferred examples of formula XIII are the following compounds:
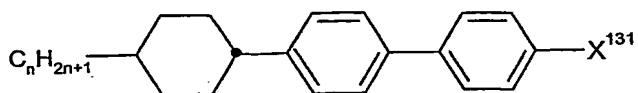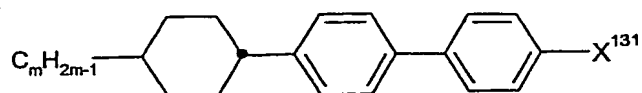

XIII-1

XIII-2

XIII-3

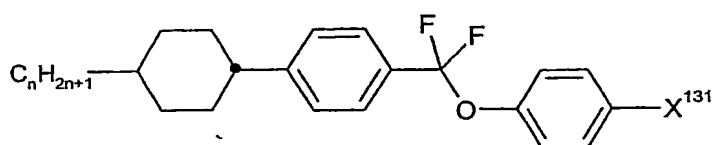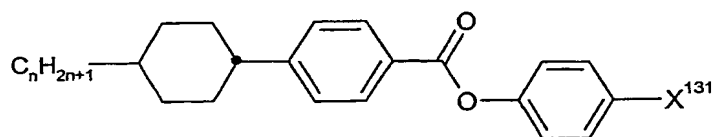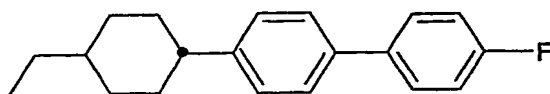Preferred compounds of formula XIV are compounds of the following formulas:
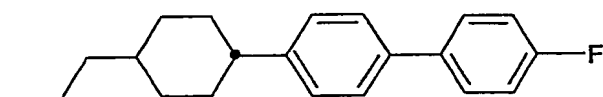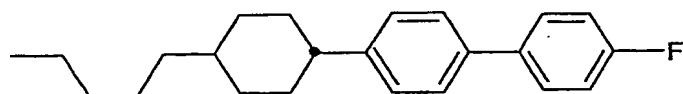

XIVA

XIVB

XIVC

XIVD

with n being 1, 2, 3, 4, 5, 6, 7 or 8, preferably 2, 3, 4, 5, m being 2, 3, 4, 5, 6, 7, 8, preferably 2, 3, 4, 5, and X^{131} being F or Cl, preferably F. Preferred examples of formula XIII are the following compounds:

XIV-1

XIV-2

XIV-3

Compounds of formulas XIII and XIV are usually used in the liquid crystal composition according to the invention in a total amount of 0 to about 40 weight%, preferably in a total amount of up to 20 weight% and more preferably in a total amount of up to 10 weight%. Compounds of each formula XIII and XIV may be present in a single composition although it is preferred that compounds of only one of these formulas are contained in a specific liquid crystal mixture of the present invention.

A specific liquid crystal composition for use in a bistable liquid crystal device may comprise compounds selected from formulas III to VIII (which are, for the sake of simplicity, denoted hereinafter as "Group A") and compounds selected from formulas IX to XII (which are, for the sake of simplicity, denoted hereinafter as "Group B") and compounds selected from formulas XIII and XIV (which are, for the sake of simplicity, denoted

hereinafter as "Group C") at the same time. However, this is not specifically required and in some cases it is even preferred that a specific mixture according to the present invention may comprise only compounds of one or two of the Groups A, B and C. It is more preferred that the liquid

5   crystal composition of the invention comprises compounds of Group A and/or Group B.

The liquid crystal composition for use in a bistable liquid crystal device according to the invention may optionally contain one or more further

10 additives known to the skilled person and described in literature. Examples of those further additives are stabilizers, chiral dopants and pleochromatic dyes. If used, they are contained in usual concentrations. The total concentration of said further additives is in the range from 0 to 15 weight%, preferably in the range from 0.1 to 10 weight%, especially preferred not

15 more than 6 weight%, based on the total weight of the composition. The concentration of each single additive is usually in the range from 0.1 to 3 weight%, if present. The concentration of said further additives and likewise constituents of the liquid crystal composition are not taken into account for the specification of the concentration of the other compounds

20 comprised in the liquid crystal composition. As chiral dopants for example cholesterylnonanoate (CN), R/S-811, R/S-1011 and R/S-2011 or CB15 (Merck KGaA, Darmstadt, Germany) may be used.

It will be acknowledged by those skilled in the art that the liquid crystal

25 composition for the use according to the invention may also comprise further (mesogenic) compounds besides those disclosed in more detail in this specification. A wide variety of mesogenic compounds may be used as long as they are not detrimental to the set of parameters important for the use of the bistable liquid crystal composition according to the invention.

30

All the compounds used in the liquid crystal composition of the bistable liquid crystal devices are either commercially available or can be readily prepared by methods known to those skilled in the art and as described in the standard text books of organic synthesis, for instance, in Houben-

35 Weyl, *Methoden der Organischen Chemie*, Georg-Thieme-Verlag, Stuttgart. The liquid crystal composition will be prepared by applying

- 52 -

standard protocols and techniques. In general, the desired amount of the minor component(s) will be dissolved in the major component, usually under elevated temperature. Alternatively, solutions of components in organic solvents like acetone, chloroform or methanol, can be mixed and
5   afterwards the solvent(s) can be removed, e.g., by distillation. Likewise, manufacturing of the bistable devices according to the invention will follow standard techniques known to the artisan.

In the context of the present invention and with respect to the compounds
10   contained in the liquid crystal composition for use in bistable liquid crystal devices and especially in zenithal bistable nematic devices of the invention the term "alkyl" means - as long as it is not defined in a different manner elsewhere in this description or the claims - straight-chain and branched hydrocarbon (aliphatic) radicals with 1 to 15 carbon atoms; the
15   hydrocarbon radicals may be unsubstituted or substituted with one or more substituents being independently selected from the group consisting of F, Cl, Br, or I. This subclass of "alkyl" containing aliphatic saturated radicals may also be designated as "alkanyl". Furthermore, "alkyl" is also meant to comprise unsubstituted or likewise substituted hydrocarbon radicals in
20   which one or more of the CH_2 groups are such replaced by -O- ("alkoxy", "oxaalkyl"), -S- ("thioalkyl"), -CH=CH- ("alkenyl"), -C≡C- ("alkynyl"), -CO-O- or -O-CO- that there are no hetero atoms (O, S) linked directly to each other. Preferably, alkyl is a straight-chain or branched saturated hydrocarbon having 1, 2, 3, 4, 5, 6, 7 or 8 carbon atoms and being
25   unsubstituted or mono- or poly-substituted with F. More preferably, alkyl is meant to be methyl, ethyl, n-propyl, i-propyl, n-butyl, i-butyl, t-butyl, n-pentyl, neopentyl, n-hexyl, n-heptyl, n-octyl; CF_3, CHF_2, CH_2F; CF_2CF_3. Most preferably, alkyl is a straight-chain hydrocarbon of up to 8 carbon atoms.

30

Since one or more CH_2 groups of an alkyl radical may be replaced by -O- as described above, the term "alkyl" also comprises "alkoxy" and "oxaalkyl" moieties. "Alkoxy" means "O-alkyl" in which the oxygen atom is directly linked to the group or ring being substituted with alkoxy and alkyl is defined
35   as above. In particular, "alkyl" in "O-alkyl" means methyl, ethyl, n-propyl, i-propyl, n-butyl, i-butyl, t-butyl, n-pentyl, neopentyl, n-hexyl, n-heptyl or n-

octyl, whereby alkyl is optionally substituted with F. Most preferably, alkoxy is $-OCH_3$, $-OC_2H_5$, $-O-n-C_3H_7$, $-O-n-C_4H_9$, $-O-t-C_4H_9$, $-OCF_3$, $-OCHF_2$, $-OCHF$ or $-OCHFCHF_2$. In the context of the present invention the term "oxaalkyl" comprises alkyl moieties in which at least one non-terminal CH_2 group is replaced by O in such a way that there are no adjacent oxygen atoms. Preferably, oxaalkyl comprises straight-chain radicals of the formula $C_tH_{2t+1}-O-(CH_2)_u-$ in which t and u are independently of each other 1, 2, 3, 4, 5 or 6; especially t is 1 or 2 and u is an integer from 1 to 6.

If one or more of the CH_2 groups of alkyl are replaced by sulphur a "thioalkyl" radical is obtained. Thioalkyl comprises alkyl moieties in which at least one terminal or non-terminal CH_2 group is replaced by S (sulphur) in such a way that there are no adjacent sulphur atoms. Preferably, thioalkyl comprises straight-chain radicals of the formula $C_tH_{2t+1}-S-(CH_2)_u-$ in which t is 1, 2, 3, 4, 5 or 6 and u is 0, 1, 2, 3, 4, 5 or 6; especially t is 1 or 2 and u is zero or an integer from 1 to 6.

In the context of the present invention the term "alkenyl" means an alkyl radical in which one or more -CH=CH- moieties are present. When two -CH=CH- moieties are present the radical may also be designated as "alkadienyl". An alkenyl radical may comprise 2 to 15 carbon atoms and may be straight-chain or branched. It can be unsubstituted or mono- or polysubstituted with F, Cl, Br, or I; one or more of its CH_2 groups may be replaced independently of each other by -O-, -S-, -C≡C-, -CO-O-, -OC-O- such that there are no hetero atoms linked directly to each other. If the alkenyl CH=CH moiety is not a terminal CH_2=CH- group it may exist in two configurations, namely the E-isomer and the Z-isomer. In general, the E-isomer (trans) is preferred. Preferably, alkenyl contains 2, 3, 4, 5, 6 or 7 carbon atoms and means vinyl, 1E-propenyl, 1E-butenyl, 1E-pentenyl, 1E-hexenyl, 1E-heptenyl, 2-propenyl, 2E-butenyl, 2E-pentenyl, 2E-hexenyl, 2E-heptenyl, 3-butenyl, 3E-pentenyl, 3E-hexenyl, 3E-heptenyl, 4-pentenyl, 4Z-hexenyl, 4E-hexenyl, 4Z-heptenyl, 5-hexenyl and 6-heptenyl. More preferred alkenyl is vinyl, 1E-propenyl, 3E-butenyl.

In the case one or more CH_2 alkyl groups are replaced by -C≡C- an alkynyl radical is obtained. Also the replacement of one or more CH_2 alkyl groups

by -CO-O- or -O-CO- is possible. The following of these radicals are preferred: acetyloxy, propionyloxy, butyryloxy, pentanoyloxy, hexanoyloxy, acetyloxymethyl, propionyloxymethyl, butyryloxymethyl, pentanoyloxymethyl, 2-acetyloxyethyl, 2-propionyloxyethyl, 2-butyryloxyethyl, 2-acetyloxypropyl, 3-propionyloxypropyl, 4-acetyloxybutyl, methoxycarbonyl, ethoxycarbonyl, propoxycarbonyl, butoxycarbonyl, pentoxycarbonyl, methoxycarbonylmethyl, ethoxycarbonylmethyl, propoxycarbonylmethyl, butoxycarbonylmethyl, 2-(methoxycarbonyl)ethyl, 2-(ethoxycarbonyl)ethyl, 2-(propoxycarbonyl)-ethyl, 3-(methoxycarbonyl)-propyl, 3-(ethoxy-carbonyl)-propyl or 4-(methoxycarbonyl)-butyl.

For the purpose of this invention the term "halogen" comprises fluorine (F), chlorine (Cl), bromine (Br) and/or iodine (I).

In the context of the present invention halogen substituted radicals like, for instance, halogen substituted alkyl, alkanyl, alkoxy and alkenyl radicals may also be designated as "halogenalkyl", "halogenalkanyl", "halogenalkoxy" and "halogenalkenyl", respectively. For instance, if halogen is F, a fluoro-substituted alkyl may be designated as "fluoroalkyl". The term "perhalogen", e.g. "perfluoro" designates a radical in which all of the hydrogen substituents of the radical are replaced by halogen, e.g. fluor. If only some of the hydrogens atoms are replaced by halogen, it is preferred that they are replaced at the ω-position of that radical like, for example, in -CH$_2$CF$_3$.

In the present description and the following examples the structures of the mesogenic compounds disclosed are described by using acronyms. Said acronyms can be transformed into chemical formulas according to Tables A and B. In these tables, radicals C$_n$H$_{2n+1}$ and C$_m$H$_{2m+1}$ are straight-chain alkyl radicals having n and m carbon atoms, respectively. Alkenyl radicals have the trans configuration. The codes according to Table B are self-evident. In Table A, only the acronym for the parent structure is given. In individual cases, the acronym for the parent structure is followed, usually separated by a hyphen, by a code for the substituents R^1, R^2, L^1 and L^2 as given below:

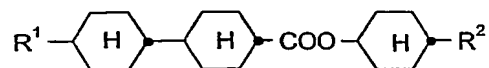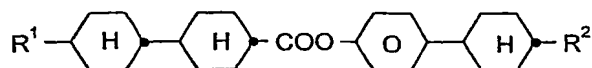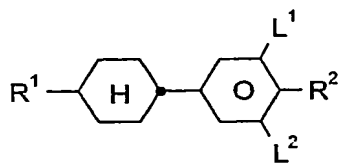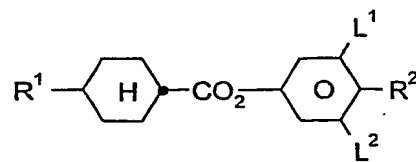| Code of R^1, R^2, L^1, L^2	R^1	R^2	L^1	L^2
n	C_nH_{2n+1}	CN	H	H
nm	C_nH_{2n+1}	C_mH_{2m+1}	H	H
nOm	C_nH_{2n+1}	OC_mH_{2m+1}	H	H
nF	C_nH_{2n+1}	F	H	H
nN.F	C_nH_{2n+1}	CN	F	H
nN.F.F	C_nH_{2n+1}	CN	F	F
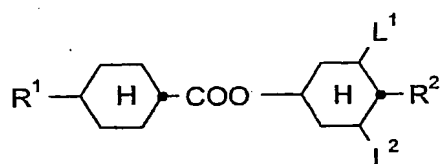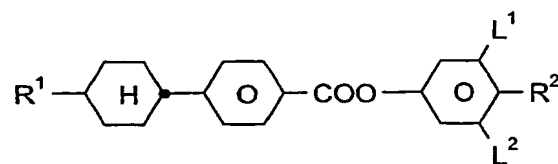
Table A:

OS

HP

CH

CCPC

PCH

D

Table B:

C_nH_{2n+1} —[H]—[O]—[O]—[H]— C_mH_{2m+1}

5   **CBC-nm**

C_nH_{2n+1} —[H]—[O]—[O]—[H]— C_mH_{2m+1}
                          F

10   **CBC-nmF**

C_nH_{2n+1} —[H]—[H]—COO—[O]— C_mH_{2m+1}

15   **CP-nm**

C_nH_{2n+1} —[H]—[H]—COO—[O]— F, F, F

20   **CCZU-n-F**

C_nH_{2n+1} —[H]—[H]— ⟋

25   **CC-n-V**

C_nH_{2n+1} —[H]—[H]— C_mH_{2m+1}

30   **CC-n-Vm**

C_nH_{2n+1} —[H]—[H]—[O]— OCF_3
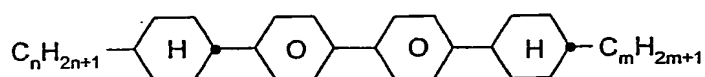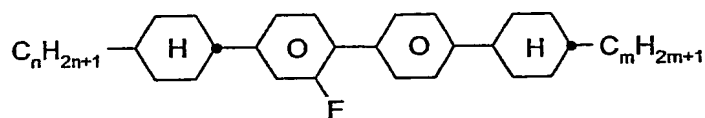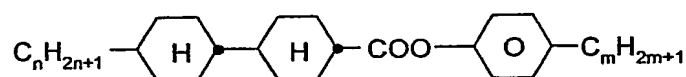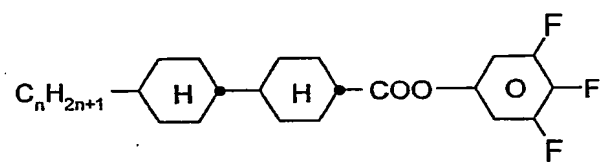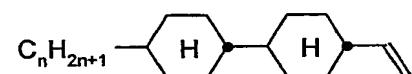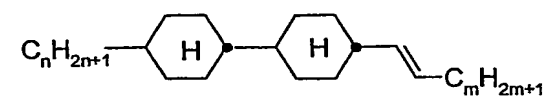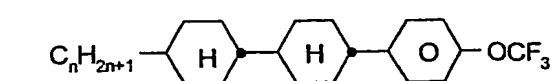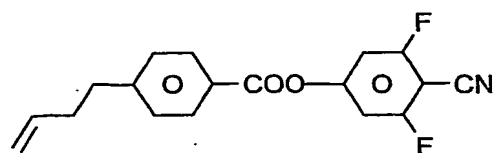
35   **CCP-n-OCF3**   **PZU-V2-N**
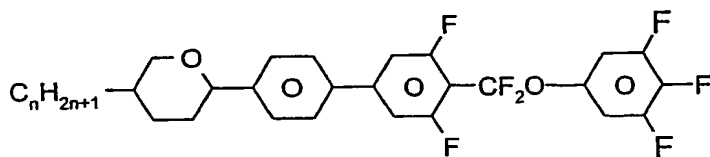
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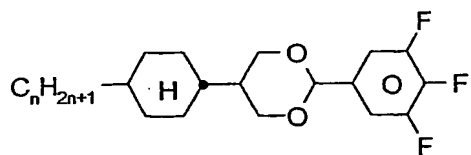
5   **CDU-n-F**
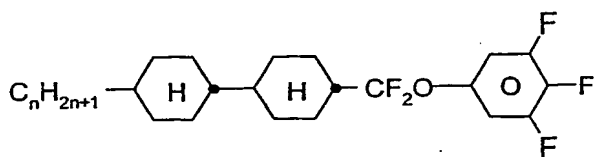
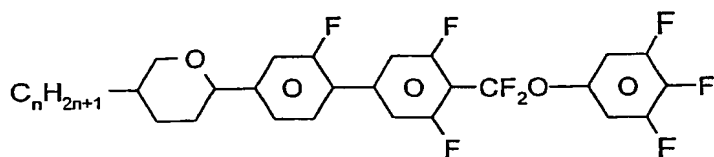10   **CCQU-n-F**
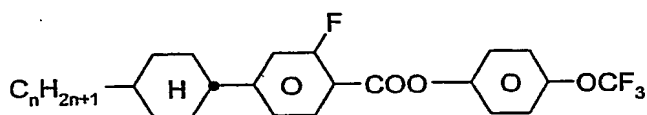
15   **CGZP-n-OT**
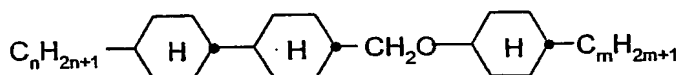
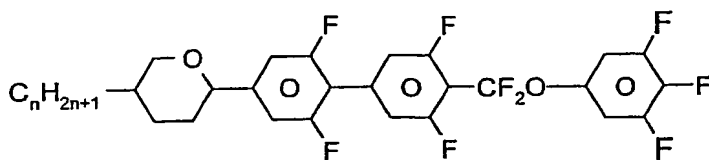20   **CCOC-n-m**
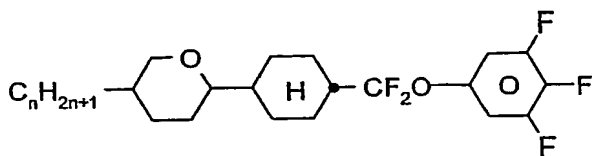
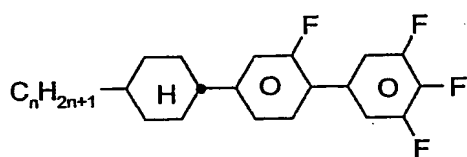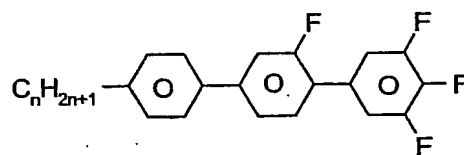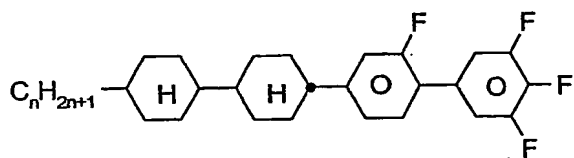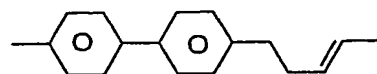25   **ACQU-n-F**

30   **APUQU-n-F**

35

AGUQU-n-F
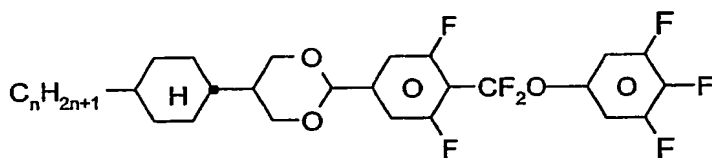
5

AUUQU-n-F

10

CDUQU-n-F

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CGU-n-F

PGU-n-F

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CCGU-n-F

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PP-1-2V1

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C_nH_{2n+1} —(H)—(H)—(O)— F, F, F

CCP-nF.F.F

C_nH_{2n+1} —(H)—(O)—(O)— F, F, F

BCH-nF.F.F

C_nH_{2n+1} —(H)—(O)—(O)— F, F

BCH-nF.F

—(H)—(H)—(O)— F, F

CCG-V-F

C_nH_{2n+1} —(H)—(H)—C_2H_4—(O)— F, F

ECCP-nF.F

C_nH_{2n+1} —(O)—(O)—(O)— F, F, F
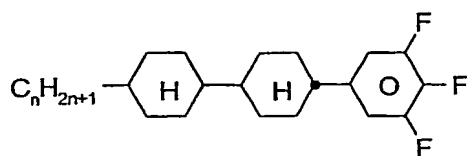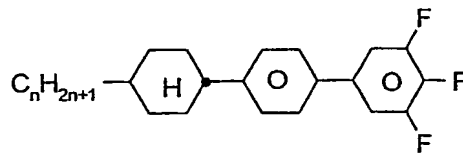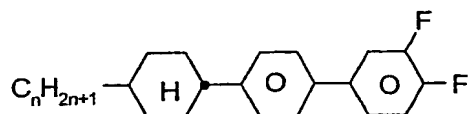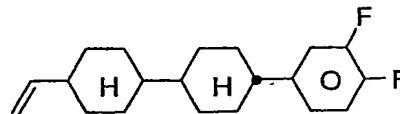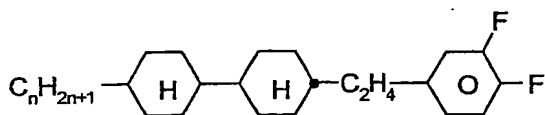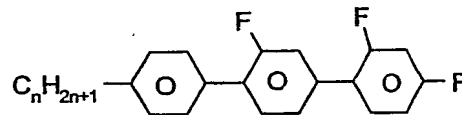
PGIGI-n-F

C_nH_{2n+1} —(H)—(H)—CF_2O—(O)— F, F
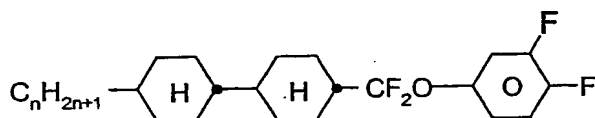
CCQG-n-F

Table C:

Table C shows dopants optionally present in the liquid crystal compositions for use in the zenithal bistable nematic devices of the invention.

C_2H_5-$\overset{*}{C}H$-CH_2O—(O)—(O)—CN
|
CH_3

C15

C_2H_5-$\overset{*}{C}H$-CH_2—(O)—(O)—CN
|
CH_3

CB 15

C_6H_{13}-$\overset{*}{C}H$-O—(O)—C(=O)O—(O)—C_5H_{11}
|
CH_3

CM21

C_6H_{13}O—(O)—C(=O)O—(O)—C(=O)O—$\overset{*}{C}H$-C_6H_{13}, CH_3

R/S-811

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CM 44   **CM 45**

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CM 47

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CN

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R/S-2011

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R/S-1011

R/S-3011

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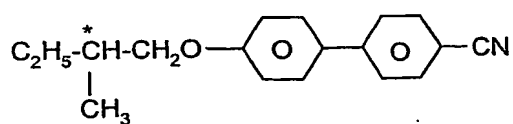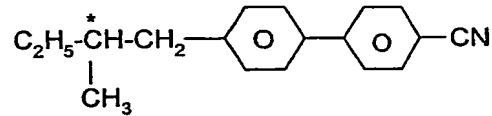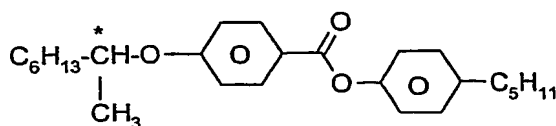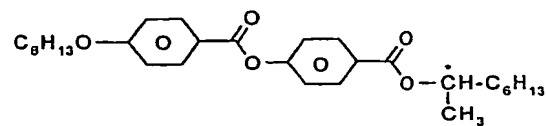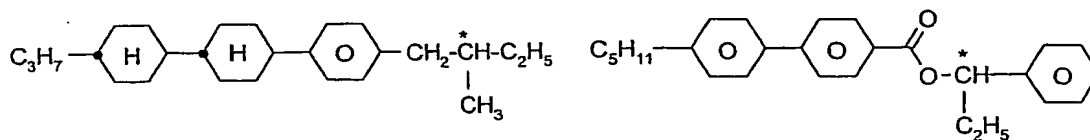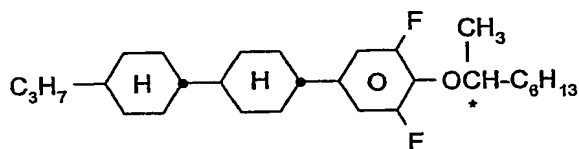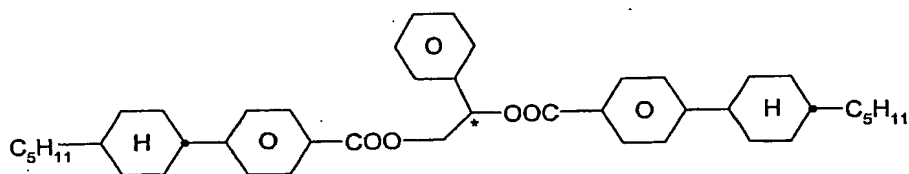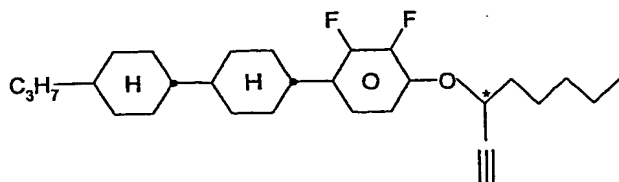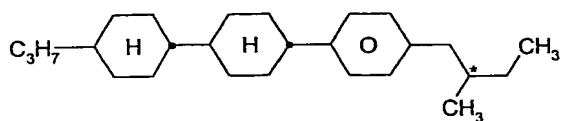
5

Table D:

Table D shows stabilizers optionally present in the liquid crystal
10 compositions for use in the zenithal bistable nematic devices of the
invention.

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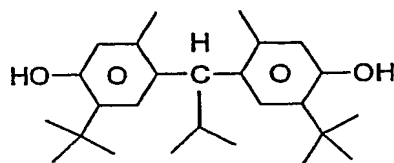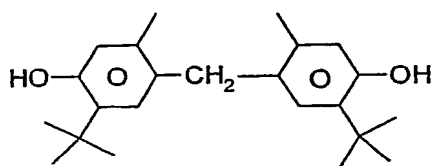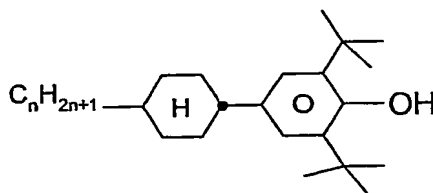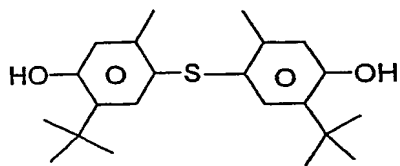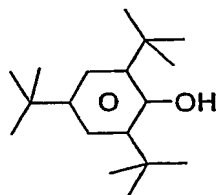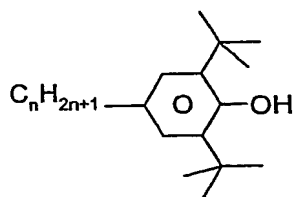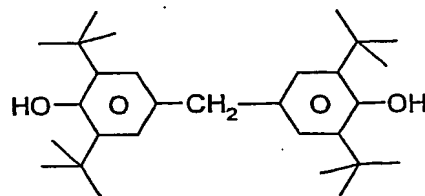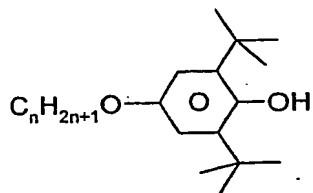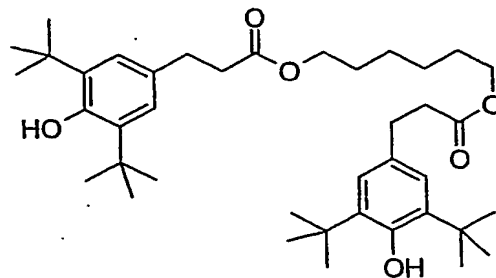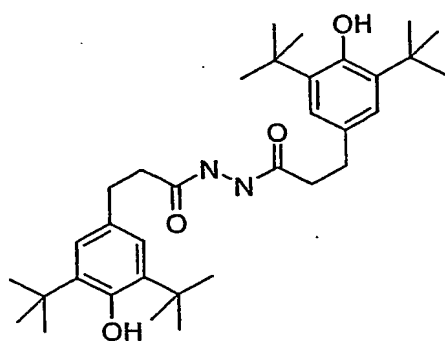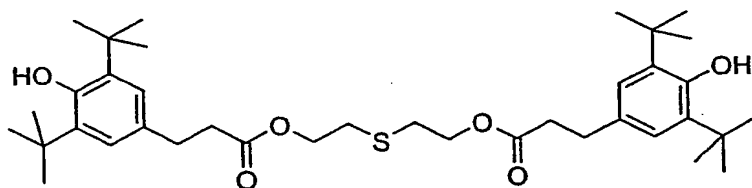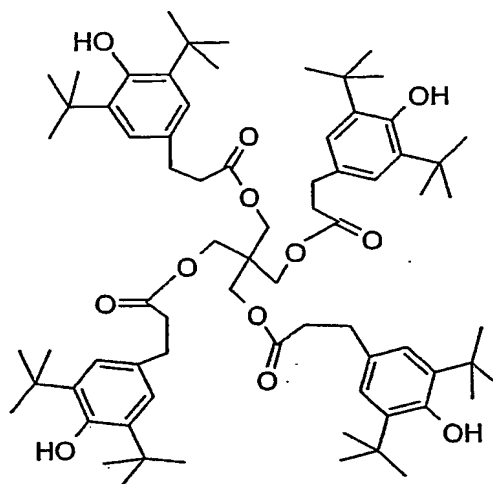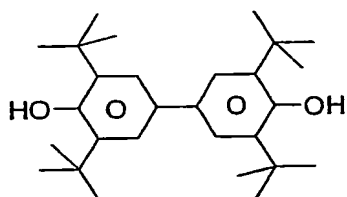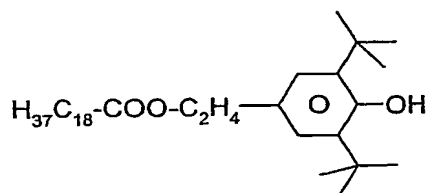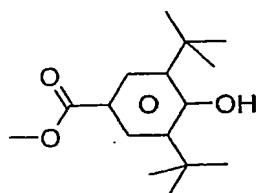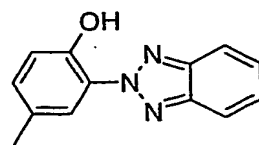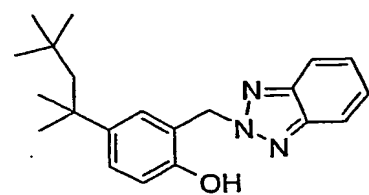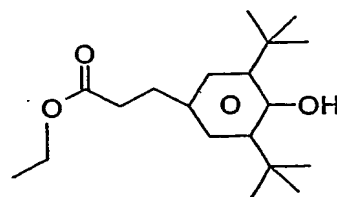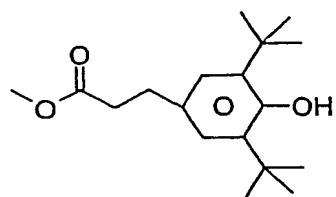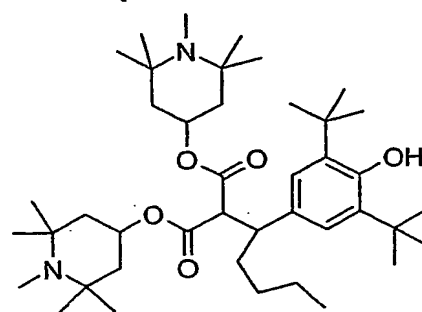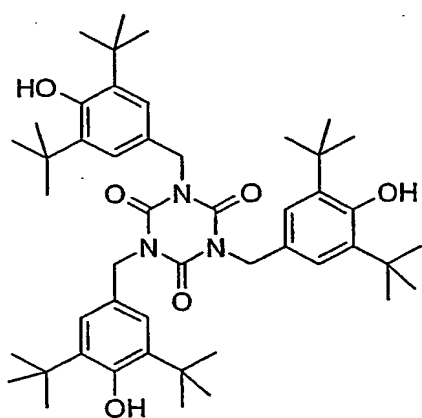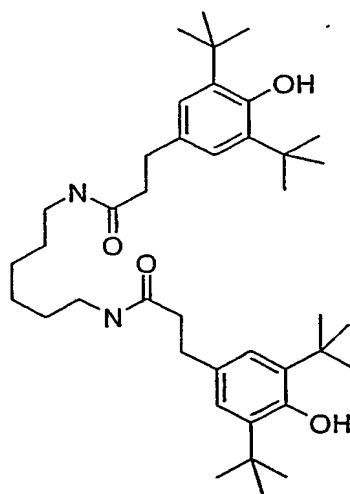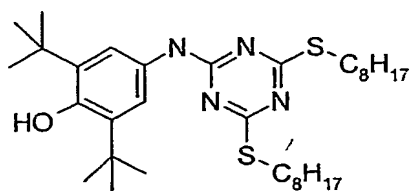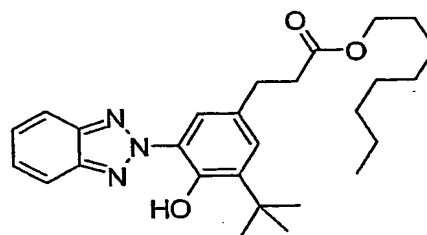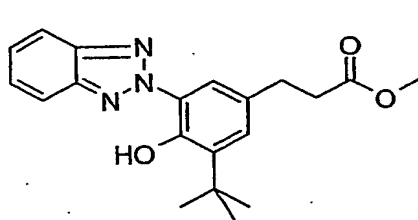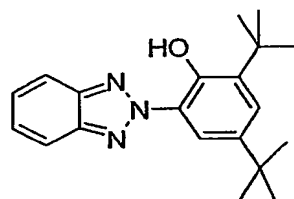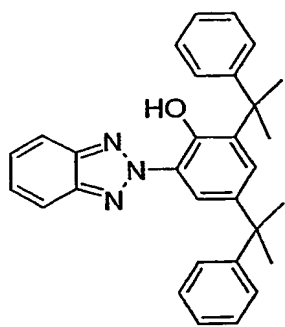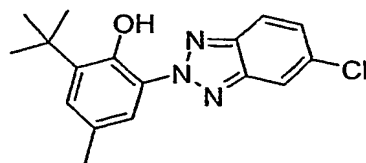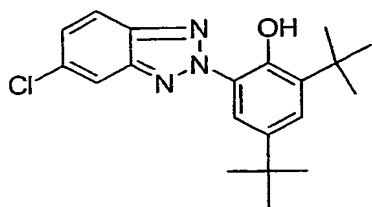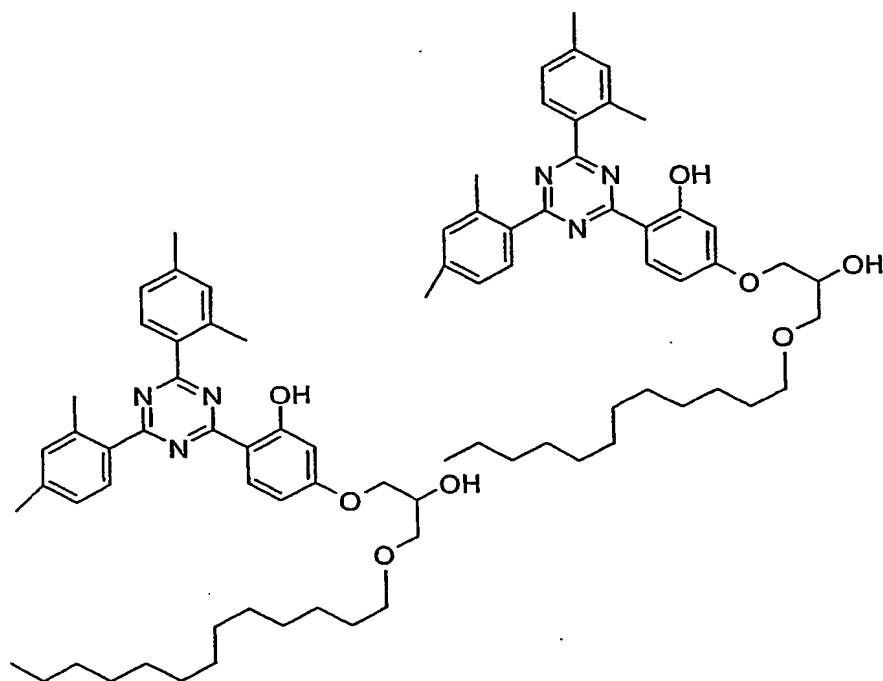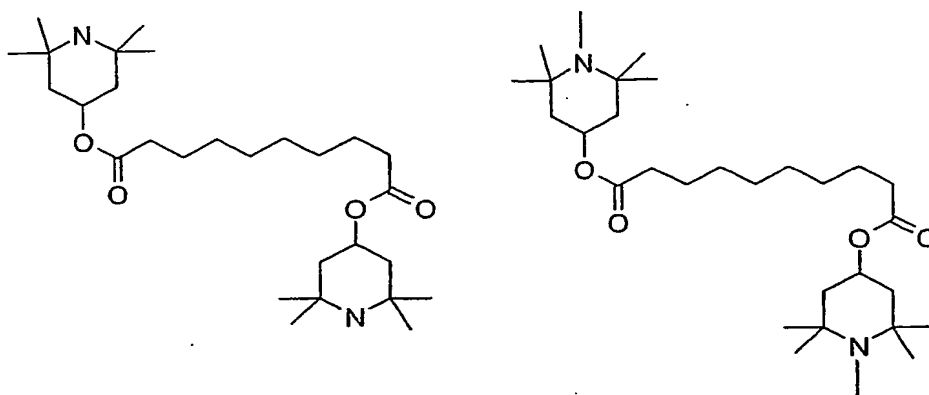
Percentages given herein are weight% and generally related to the total amount of a composition or mixture except stated otherwise.

15 Temperatures are given in degree Celsius (°C) unless stated otherwise. T_{NI} means the clearing point at which a nematic medium becomes isotropic. Δn is the optical anisotropy (birefringence) (at 589 nm, 20 °C). $\Delta\varepsilon$ means the dielectric anisotropy (at 1 k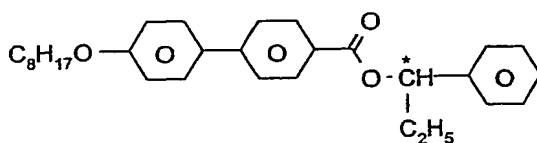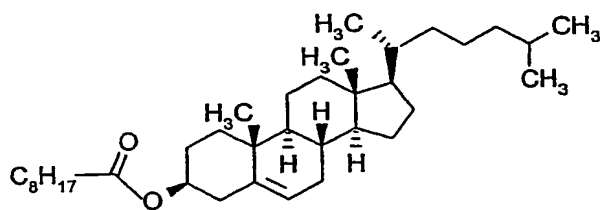Hz, 20 °C). K_1 is the splay elastic constant, and K_3 is the bend elastic constant both given in pN. Electrooptical data has been determined in a vertically aligned zenithal

20 bistable nematic cell. Except stated otherwise the measurements have been performed at 20 °C. V_{opt} is the optimum operating voltage (in V) derived from the corrected switching field $E_{LC@100\mu s}$ (at 25 °C; in zenithal bistable test cells with the actual cell gap d of about 4 to about 5 μm; 100 μs pulse) by $V_{opt} = E_{LC@100\mu s}\cdot d_{opt}$ (with d_{opt} (in μm) being $\lambda/(2\Delta n)$ + 0.4 for

25 $\Delta n < 0.11$ and $\lambda\sqrt{3}/(2\Delta n)$ +0.4 for $\Delta n > 0.11$; $\lambda = 0.555$ μm, and the 0.4 factor is an empirical correction factor), if not stated otherwise. Optical response time $\tau_{opt}$ (in ms) is calculated from $\tau_{opt} = \tau\cdot d^2_{opt}/d^2$ with τ being the experimental response time, d_{opt} being as defined above and d being the experimental cell gap.

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The following Examples should further illustrate the present invention as described above and in the claims but not meant to restrict its scope.

Examples

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- 66 -

Test samples were prepared by weighing out the appropriate weight amounts (percentage weight/weight) of the individual components. The sample was then homogenised by heating into the isotropic phase and thoroughly mixing. The mixture was then stirred with a given concentration

5   of alumina and then filtered (0.2μm) to just leave the liquid crystal mixture. The nematic to isotropic transition temperature (or clearing point, T_{NI}), dielectric anisotropy ($\Delta\varepsilon$), birefringence (Δn), splay and bend elastic constants (K_1 and K_3), and rotational viscosities (γ_1) were determined as described in the Merck brochure "Physical Properties of Liquid Crystals –

10   Description of the measurement methods", ed. W. Becker (1998). Values for single compounds are extrapolated from those determined using a known concentration (usually 10 weight% of the single compound) in a standard host mixture ZLI-4792 (Merck KGaA, Darmstadt, Germany) for which the initial mixture values are also known. The electrooptical

15   performance of each mixture in a zentihal bistable nematic device was measured using a simple experimental set-up and the vertically aligned type test cells. This required a transmissive mode microscope with a mounted photo-detector connected to an oscilloscope. This allowed the transmission through crossed polarisers to be monitored. The test cell was

20   mounted on a heating stage under the microscope to permit measurements at 25°C. Bipolar electrical pulses (of varying duration and voltage) were used to ensure that there was no net d.c. voltage applied to the cell. The trailing edge (and so polarity) of each pulse therefore determined the final switched state (depending on the duration and

25   voltage). Two signal generators were necessary to ensure that the correct initial state is first selected, with the first signal triggering the second (with an appropriate phase difference). Both signals were amplified by passing the output of the signal generators through an amplifier before being connected to the test cell. For the B-W transition, the voltages required for

30   10 and 90% transmission changes and reverse 90 and 10% transmission changes were measured for various pulse durations. For the W-B transition, the voltages required for 90 and 10% transmission changes only were measured for various pulse durations. These levels were set on the oscilloscope once the 0 and 100% transmission levels were known (i.e.

35   black and white), and they could also be used to determine the optical response time of the transition (for 10 to 90% transmission changes).

$E_{LC@100\mu s}$ was determined from the average switching field of both the W-B and B-W transitions in these examples.

Vertically aligned type test cells having a standard homeotropic alignment layer on one substrate and a grating plus homeotropic alignment layer on the other substrate (available from ZBD Displays Ltd., Malvern, UK) were used with cell gaps typically 4-5μm, in transmissive mode and with crossed polarisers. Due to the varying cell gaps and different mixture Δn values, the retardation was not optimised but this is not crucial as it only decreases the contrast.

Example 1

Compound	Amount (wt%)	T_{NI} (°C)	98.0
CDU-2-F	10	Δε	13.7
CDU-3-F	10	Δn	0.0685
CDU-5-F	10	K_1 (pN)	10.6
CCZU-2-F	6	K_3 (pN)	17.7
CCZU-3-F	13		
CCZU-5-F	6		
CCQU-2-F	10	τ_{opt} (ms)	36
CCQU-3-F	10	d (μm)	4.7
CCQU-5-F	10	d_{opt} (μm)	4.5
CCOC-3-3	5	$V_{opt}^{100\mu s}$ (V)	12.8
CCOC-3-5	5	$V_{opt}^{1000\mu s}$ (V)	9.4
CCOC-4-3	5	$V_{opt}^{10000\mu s}$ (V)	5.7
Total	100		

Example 2

Compound	Amount (wt%)	T_{NI} (°C)	100.5
CDU-2-F	10	$\Delta\varepsilon$	12.4
CDU-3-F	10	Δn	0.0716
CDU-5-F	10	K_1 (pN)	11.4
CCZU-2-F	5	K_3 (pN)	17.1
CCZU-3-F	10		
CCZU-5-F	5		
CCQU-2-F	10	τ_{opt} (ms)	33
CCQU-3-F	10	d (µm)	4.5
CCQU-5-F	10	d_{opt} (µm)	4.3
CC-5-V	12	$V_{opt}^{100\mu s}$ (V)	14.4
CCPC-33	3	$V_{opt}^{1000\mu s}$ (V)	10.3
CCPC-34	3	$V_{opt}^{10000\mu s}$ (V)	8.0
CCPC-35	2		
Total	100		

Example 3

Compound	Amount (wt%)	T_{NI} (°C)	93.8
PGU-2-F	10	$\Delta\varepsilon$	17.3
PGU-3-F	10	Δn	0.1350
PGU-5-F	10	K_1 (pN)	12.0
CCGU-3-F	5	K_3 (pN)	16.0
CCZU-2-F	5		
CCZU-3-F	10		
CCZU-5-F	5	τ_{opt} (ms)	22
CCQU-2-F	10	d (µm)	4.7
CCQU-3-F	10	d_{opt} (µm)	4.0
CCQU-5-F	10	$V_{opt}^{100\mu s}$ (V)	18.6
PP-1-2V1	9	$V_{opt}^{1000\mu s}$ (V)	15.9
CCPC-33	4	$V_{opt}^{10000\mu s}$ (V)	15.0
CCPC-34	1		
CCPC-35	1		
Total	100		

Example 4

Compound	Amount (wt%)		
		T_{NI} (°C)	100.0
CGU-2-F	10	$\Delta\varepsilon$	14.9
CGU-3-F	10	Δn	0.0931
CGU-5-F	10	K_1 (pN)	8.6
CCGU-3-F	5	K_3 (pN)	17.3
CCZU-2-F	7		
CCZU-3-F	15		
CCZU-5-F	7	τ_{opt} (ms)	19
CCQU-2-F	10	d (µm)	4.4
CCQU-3-F	10	d_{opt} (µm)	3.4
CCQU-5-F	10	$V_{opt}^{100\mu s}$ (V)	8.1
CCPC-33	2	$V_{opt}^{1000\mu s}$ (V)	5.0
CCPC-34	2	$V_{opt}^{10000\mu s}$ (V)	4.0
CCPC-35	2		
Total	100		

Example 5

Compound	Amount (wt%)		
		T_{NI} (°C)	90.8
PGU-2-F	10	$\Delta\varepsilon$	15.9
PGU-3-F	10	Δn	0.1465
PGU-5-F	10	K_1 (pN)	9.2
CGU-2-F	10	K_3 (pN)	12.5
CGU-3-F	10		
CGU-5-F	10		
CCGU-3-F	5	τ_{opt} (ms)	29
BCH-3F.F.F	10	d (µm)	4.4
BCH-5F.F.F	10	d_{opt} (µm)	3.7
CCPC-33	5	$V_{opt}^{100\mu s}$ (V)	16.2
CCPC-34	5	$V_{opt}^{1000\mu s}$ (V)	14.0
CCPC-35	5	$V_{opt}^{10000\mu s}$ (V)	13.5
Total	100		

Example 6

Compound	Amount (wt%)	T_{NI} (°C)	91.8
PGU-2-F	10	$\Delta\varepsilon$	17.4
PGU-3-F	10	Δn	0.1338
PGU-5-F	10	K_1 (pN)	8.1
CGU-2-F	10	K_3 (pN)	13.2
CGU-3-F	10		
CGU-5-F	10		
CCGU-3-F	3	τ_{opt} (ms)	30
CCZU-2-F	6	d (µm)	4.4
CCZU-3-F	13	d_{opt} (µm)	4.0
CCZU-5-F	6	$V_{opt}^{100\mu s}$ (V)	15.8
CCPC-33	4	$V_{opt}^{1000\mu s}$ (V)	13.4
CCPC-34	4	$V_{opt}^{10000\mu s}$ (V)	12.8
CCPC-35	4		
Total	100		

Example 7

Compound	Amount (wt%)	T_{NI} (°C)	91.2
CDU-2-F	10	$\Delta\varepsilon$	15.4
CDU-3-F	10.5	Δn	0.0933
CDU-5-F	9.5	K_1 (pN)	7.4
CGU-2-F	10	K_3 (pN)	14.8
CGU-3-F	10		
CGU-5-F	10		
CCGU-3-F	5	τ_{opt} (ms)	22
CCZU-2-F	6.5	d (µm)	4.7
CCZU-3-F	13	d_{opt} (µm)	3.4
CCZU-5-F	6.5	$V_{opt}^{100\mu s}$ (V)	9.7
CCPC-33	3	$V_{opt}^{1000\mu s}$ (V)	7.4
CCPC-34	4	$V_{opt}^{10000\mu s}$ (V)	5.9
CCPC-35	2		
Total	100		

Example 8

Compound	Amount (wt%)	T_{NI} (°C)	92.8
PGU-2-F	10	$\Delta\varepsilon$	16.2
PGU-3-F	10	Δn	0.1134
PGU-5-F	10	K_1 (pN)	9.6
CCGU-3-F	2	K_3 (pN)	14.1
CCZU-2-F	6		
CCZU-3-F	11		
CCZU-5-F	6	τ_{opt} (ms)	35
CCQU-2-F	10	d (µm)	4.2
CCQU-3-F	10	d_{opt} (µm)	4.6
CCQU-5-F	10	$V_{opt}^{100\mu s}$ (V)	13.7
CCOC-3-3	5	$V_{opt}^{1000\mu s}$ (V)	10.6
CCOC-3-5	5	$V_{opt}^{10000\mu s}$ (V)	8.9
CCOC-4-3	5		
Total	100		

Example 9

Compound	Amount (wt%)	T_{NI} (°C)	92.6
CDU-2-F	10	$\Delta\varepsilon$	13.6
CDU-3-F	10	Δn	0.0929
CDU-5-F	10	K_1 (pN)	9.9
CGU-2-F	10	K_3 (pN)	14.0
CGU-3-F	10		
CGU-5-F	10		
CCGU-3-F	4	τ_{opt} (ms)	27
CCP-2F.F.F	8	d (µm)	4.2
CCP-3F.F.F	8	d_{opt} (µm)	3.4
CCP-5F.F.F	4	$V_{opt}^{100\mu s}$ (V)	13.5
CC-5-V	2	$V_{opt}^{1000\mu s}$ (V)	8.7
CCPC-33	5	$V_{opt}^{10000\mu s}$ (V)	7.2
CCPC-34	5		
CCPC-35	4		
Total	100		

Example 10

Compound	Amount (wt%)		
		T_{NI} (°C)	98.0
AUUQU-3-F	6	$\Delta\varepsilon$	18.9
AGUQU-3-F	6	Δn	0.0928
APUQU-2-F	6	K_1 (pN)	9.8
CGU-2-F	5	K_3 (pN)	15.2
CGU-3-F	5		
CGU-5-F	5		
CCZU-2-F	5.5	τ_{opt} (ms)	29
CCZU-3-F	10.5	d (µm)	4.1
CCZU-5-F	5.5	d_{opt} (µm)	3.4
CCQU-2-F	10	$V_{opt}^{100\mu s}$ (V)	9.9
CCQU-3-F	10	$V_{opt}^{1000\mu s}$ (V)	6.5
CCQU-5-F	10	$V_{opt}^{10000\mu s}$ (V)	5.0
CC-5-V	9.5		
CCPC-33	2		
CCPC-34	2		
CCPC-35	2		
Total	100		

Example 11

Compound	Amount (wt%)	T_{NI} (°C)	96.6
CDUQU-3-F	6	$\Delta\epsilon$	16.2
CGU-2-F	10	Δn	0.0930
CGU-3-F	10	K_1 (pN)	8.5
CGU-5-F	10	K_3 (pN)	17.5
CCGU-3-F	2		
CCZU-2-F	6.5		
CCZU-3-F	13	τ_{opt} (ms)	31
CCZU-5-F	6.5	d (µm)	4.6
CCQU-2-F	10	d_{opt} (µm)	3.4
CCQU-3-F	10	$V_{opt}^{100\mu s}$ (V)	9.7
CCQU-5-F	10	$V_{opt}^{1000\mu s}$ (V)	6.4
CCPC-33	2	$V_{opt}^{10000\mu s}$ (V)	5.1
CCPC-34	2		
CCPC-35	2		
Total	100		

Example 12

Compound	Amount (wt%)	T_{NI} (°C)	96.8
CGU-2-F	10	$\Delta\epsilon$	15.5
CGU-3-F	10	Δn	0.0934
CGU-5-F	10	K_1 (pN)	8.5
CCGU-3-F	5	K_3 (pN)	16.9
ACQU-5-F	10		
CCZU-2-F	6		
CCZU-3-F	13	τ_{opt} (ms)	28
CCZU-5-F	6	d (µm)	4.6
CCQU-2-F	8	d_{opt} (µm)	3.4
CCQU-3-F	8	$V_{opt}^{100\mu s}$ (V)	9.2
CCQU-5-F	8	$V_{opt}^{1000\mu s}$ (V)	5.6
CCPC-33	2	$V_{opt}^{10000\mu s}$ (V)	4.3
CCPC-34	2		
CCPC-35	2		
Total	100		

Example 13

Compound	Amount (wt%)	T_{NI} (°C)	94.9
CGU-2-F	10	$\Delta\varepsilon$	13.1
CGU-3-F	10	Δn	0.0888
CGU-5-F	10	K_1 (pN)	9.3
CCGU-3-F	5	K_3 (pN)	16.2
CCZU-2-F	5	$V_{opt}^{100\mu s}$ (V)	7.2
CCZU-3-F	10		
CCZU-5-F	5	τ_{opt} (ms)	7
CCQU-2-F	10	d (μm)	4.0
CCQU-3-F	10	d_{opt} (μm)	3.5
CCQU-5-F	10		
CCOC-3-3	5	$V_{opt}^{1000\mu s}$ (V)	4.4
CCOC-3-5	5	$V_{opt}^{10000\mu s}$ (V)	2.8
CCOC-4-3	5		
Total	100		

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Example 14

Compound	Amount (wt%)	T_{NI} (°C)	98.1
AUUQU-3-F	5	$\Delta\varepsilon$	22.9
AGUQU-3-F	5	Δn	0.0926
APUQU-2-F	5	K_1 (pN)	8.3
CDUQU-3-F	5	K_3 (pN)	17.9
CGU-2-F	5	$V_{opt}^{100\mu s}$ (V)	5.1
CGU-3-F	5		
CGU-5-F	5	τ_{opt} (ms)	6
ACQU-5-F	10	d (µm)	4.1
CCZU-2-F	5	d_{opt} (µm)	3.4
CCZU-3-F	10		
CCZU-5-F	5	$V_{opt}^{1000\mu s}$ (V)	3.1
CCQU-2-F	10	$V_{opt}^{10000\mu s}$ (V)	2.3
CCQU-3-F	10		
CCQU-5-F	10		
CCPC-33	2		
CCPC-34	2		
CCPC-35	1		
Total	100		

Example 15

Compound	Amount (wt%)	T_{NI} (°C)	70.3
CGU-2-F	11	$\Delta\varepsilon$	12.5
CGU-3-F	11	Δn	0.1084
CGU-5-F	11	K_1 (pN)	7.6
CCZU-2-F	6	K_3 (pN)	11.2
CCZU-3-F	14		
CCZU-5-F	6		
BCH-3F.F.F	10	τ_{opt} (ms)	16
BCH-5F.F.F	14	d (µm)	4.7
BCH-3F.F	6	d_{opt} (µm)	3.0
ECCP-5F.F	8	$V_{opt}^{100\mu s}$ (V)	8.6
CBC-33F	3	$V_{opt}^{1000\mu s}$ (V)	5.2
Total	100	$V_{opt}^{10000\mu s}$ (V)	3.8

Example 16

Compound	Amount (wt%)	T_{NI} (°C)	98.8
CGU-2-F	10	$\Delta\varepsilon$	10.3
CGU-3-F	10	Δn	0.0912
CGU-5-F	10	K_1 (pN)	11.3
CCGU-3-F	6	K_3 (pN)	15.6
CCZU-2-F	5		
CCZU-3-F	10		
CCZU-5-F	5	τ_{opt} (ms)	20
CCQU-2-F	5	d (µm)	4.7
CCQU-3-F	5	d_{opt} (µm)	3.4
CCQU-5-F	5	$V_{opt}^{100\mu s}$ (V)	15.4
CC-5-V	20	$V_{opt}^{1000\mu s}$ (V)	10.4
CCPC-33	3	$V_{opt}^{10000\mu s}$ (V)	8.6
CCPC-34	3		
CCPC-35	3		
Total	100		

Example 17

Compound	Amount (wt%)	T_{NI} (°C)	90.0
CGU-2-F	10	$\Delta\varepsilon$	11.2
CGU-3-F	10	Δn	0.1208
CGU-5-F	10	K_1 (pN)	8.3
CCGU-3-F	3	K_3 (pN)	14.4
CCZU-2-F	7		
CCZU-3-F	15		
CCZU-5-F	7	τ_{opt} (ms)	45
BCH-2F.F	8	d (µm)	4.5
BCH-3F.F	8	d_{opt} (µm)	4.4
BCH-5F.F	8	$V_{opt}^{100\mu s}$ (V)	18.4
PGIGI-3-F	8	$V_{opt}^{1000\mu s}$ (V)	14.5
CCPC-33	2	$V_{opt}^{10000\mu s}$ (V)	12.8
CCPC-34	2		
CCPC-35	2		
Total	100		

Example 18

Compound	Amount (wt%)	T_{NI} (°C)	95.3
CGU-2-F	10	$\Delta\varepsilon$	11.1
CGU-3-F	10	Δn	0.0967
CGU-5-F	10	K_1 (pN)	10.3
CCGU-3-F	5	K_3 (pN)	14.6
CCZU-2-F	6		
CCZU-3-F	11		
CCZU-5-F	6	τ_{opt} (ms)	24
CCQU-2-F	5	d (µm)	4.6
CCQU-3-F	5	d_{opt} (µm)	3.3
CCQU-5-F	5	$V_{opt}^{100\mu s}$ (V)	17.0
D-301	5	$V_{opt}^{1000\mu s}$ (V)	14.3
D-302	5	$V_{opt}^{10000\mu s}$ (V)	13.3
D-401	5		
D-402	5		
CCPC-33	2.5		
CCPC-34	2.5		
CCPC-35	2		
Total	100		

Example 19

Compound	Amount (wt%)	T_{NI} (°C)	97.3
CGU-2-F	6	$\Delta\varepsilon$	13.9
CGU-3-F	6	Δn	0.0859
CGU-5-F	6	K_1 (pN)	8.5
CCGU-3-F	6	K_3 (pN)	17.3
CCZU-2-F	6		
CCZU-3-F	14		
CCZU-5-F	6	τ_{opt} (ms)	24
CCQU-2-F	10	d (μm)	4.7
CCQU-3-F	10	d_{opt} (μm)	3.6
CCQU-5-F	10	$V_{opt}^{100\mu s}$ (V)	7.4
CCQG-2-F	10	$V_{opt}^{1000\mu s}$ (V)	3.9
CCQG-3-F	10	$V_{opt}^{10000\mu s}$ (V)	3.0
Total	100		